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Paper No. 196

CALCULATIONS FOR SHIPS' FORMS AND THE LIGHT THROWN BY MODEL EXPERIMENTS UPON RESISTANCE, PROPULSION AND ROLLING OF SHIPS.

By

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CALCULATIONS FOR DETERMINATION OF SHIPS' LINES.

All ship calculations proper are made from the complete lines, namely, sheer, half-breadth, and body plans, or from special calculation plans derived from the lines. But in order to get out the lines in the first place, the usual methods of trial and error involve a large amount of calculation. Such drudgery could be largely reduced by the determination, once for all, before delineation, of each line to be drawn, provided this determination did not bring in too much drudgery of its own. This leads to the use of mathematical formulae of such nature and with such optional coefficients as to enable us to choose in advance the kind of line we wish with the certainty that the displacement or area will be what is desired. Some devices or formulae for lines propose to go further and give lines resulting in ships particularly easy to drive, or whose resistance can be calculated from coefficients depending upon the formulae. Such a proposition, for instance, was put forward by Herr Bauer, in 1914, before the Schiffbautechnischen Gesellschaft.*

For some fifteen years, at the U. S. Model Basin, there have been used mathematical formulae, not with the idea that they give lines of minimum resistance, but simply to obtain lines possessing desired shapes. Dealing with a large number of models annually—one hundred and fifty distinct models in

* "Harmonie der Schiffsformen" by M. H. Bauer, in the "Jahrbuch der Schiffbautechnischen Gesellschaft", 1914.

some years—even after allowing for the fact that many of them are from complete sets of lines furnished independently or derived from other lines by expansion or contraction, it would be practically impossible to accomplish the work with the force available, if it were necessary to draw each new set of lines by the trial and error method. By present methods, after a little study and practice, a competent draftsman can get out a complete set of lines giving exactly the displacement desired, using nothing from any previous vessel, in not more than five days. Most models, however, are modifications, in a desired direction, of some previous lines, and can be gotten out in less time. Practically all U. S. naval vessels designed during the last ten years have had mathematical lines.

Formulae for lines should be as simple as possible and involve the fewest possible optional coefficients. This for the reason that these quantities are not wholly independent, and the more complicated the formulae and more numerous the optional quantities, the more complicated the relations between the optional quantities which must be considered in obtaining a fair form. For water-lines and curves of sectional area we use a fifth-power parabola as the primary formula. For such a line, of given half-length and half-beam, we may choose, at will, the coefficient of fineness, the tangent or angle of inclination at the extremity, and the curvature amidships. The inclination at the midship section is in every case zero, and the water-line must have the proper half-breadth at the midship section, which, of course, is not necessarily at the center of length.

For fine sections, with sectional coefficients below 0.7, or thereabouts, a fourth-power parabola is used, the optional quantities being the coefficient of fineness of the section, the flare or tumble-home of the section at the water-line, and the dead-rise at the keel. For full sections, with sectional coefficients above 0.7, or thereabouts, we use an arc of a very well-known curve, namely, the common hyperbola. This can be made to give sections practically identical with those from the fourth-power parabola for coefficients in the vicinity of 0.7, so we can pass from one formula to the other without any difficulty. For these full sections the only optional quantities are

the coefficient of fineness and the flare or tumble-home at the water-line. The dead-rise follows from the nature of the curve, but it is found in practice that for the full sections for which the hyperbola is used, and for ships' forms as they are, the dead-rise angles resulting from the hyperbola are quite satisfactory. The trouble with mathematical formulae for sections and water-lines is that in addition to giving us the curves we want, they are capable of giving us a great many curves that we do not want, and before they can be used with satisfaction, it is necessary to determine how to use the optional coefficients in order to obtain, at will, curves such as are wanted. The details of the formulae and their applications are given in Appendix I, concerning which it may be said that, while desirable, it is not at all necessary that one using the methods should understand the mathematics of them. I would invite attention to Fig. 17, giving the body plan of a vessel with mathematical lines. Each section from keel to water-line is calculated mathematically by the methods of Appendix I, with the exception of No. 38. Sections 2 to 30, inclusive, are hyperbolic.

RESISTANCE.

When steam navigation entered upon the rapid development dating from the middle of the last century, it became necessary that former crude ideas as to the resistance of ships and methods of determining the power required to drive a given ship at a given speed should be replaced by ideas and methods more in consonance with facts.

In 1860, or later, we find leading authorities who considered that the whole resistance of a ship was due to surface friction and that for properly formed ships the wave resistance was negligible. All such ideas have now been discarded, and the present accepted ideas as regards resistance of ships are based entirely upon the work done by William Froude and his successors in model tank experiments. Although it is more than forty years since Froude built the first model tank in his garden at Torquay, England, and published most important results of experiments made there, it is only since a comparatively recent date—say the beginning of the present century—

that model tanks and their results have been generally accepted as ordinary tools of the naval architect thoroughly to be relied upon. Here and there a skeptic may exist today, but the law of comparison as applied by Froude is now generally accepted.

At the U. S. Model Basin, during the last fifteen years, the Froude methods have been applied to the models of some 189 U. S. vessels, having a total displacement of about 1,163,874 tons and a value, or cost when new, of about $443,000,000.00. In the cases of two vessels, only, have the results of the trial of the full-sized ship differed materially from what was to be expected from the model results. This was really one case, as the two vessels were sister ships. The probable cause of the discrepancy has long been known, although it acts so seldom in practice that it is apt to be forgotten.

The law of comparison, strictly speaking, requires that not only must the speed of the full-sized vessel be to the speed of the model in the ratio of the square roots of their linear dimensions, but that the pressures around the two must be in the ratio of the linear dimensions. It so happens, however, that pressure does not affect materially the resistance due to surface friction and to the formation and dispersion of waves for either model or ship. As regards the third recognized element of resistance, namely, eddying, the theoretical pressure condition must be complied with, if the eddy resistances of model and full-sized vessel are to follow the law of comparison; but in nearly all vessels the eddy resistance is not only a small factor, but consists of eddies behind struts, stern post, etc., which are comparatively little affected by pressure. But in vessels with exceptionally full sterns, we may have eddies under the quarters, with accompanying increase of resistance; while corresponding eddies do not appear in the model, although they would appear if the pressure around the model could be reduced to scale. This was apparently the condition in the case of the two vessels above referred to, which required more power than expected to obtain their designed speed.

I would not be understood as stating that the resistance of a full-sized vessel can be determined in advance with minute accuracy by model basin experiments, or by any other method now known. As a matter of fact, the resistance of any vessel

is largely due to frictional resistance. For most vessels, this factor is decidedly predominant, and we determine the frictional resistance by estimates based upon experiments made by Froude forty years ago. It is very difficult to determine with minute accuracy the actual frictional resistance of the surface of a large vessel; the workmanship, condition of plating, and other minor factors affect it appreciably, and marine growth may increase friction radically. Experiments in the U. S. Model Basin, with plates exposed to fouling, near Norfolk, Va., indicated that in seven months, from July to February, a marine growth by no means excessive, consisting mostly of barnacles, averaging in total weight when dry one-quarter of a pound per square foot, would increase the frictional resistance by as much as 210 per cent. Moderate ordinary corrosion with no appreciable fouling will also materially increase frictional resistance.

In connection with the friction of models, it may be of interest to record that the experience of the U. S. Model Basin, as regards variation of friction with temperature, does not appear to be in accord with the rather discordant results obtained in Great Britain. In the early days of the establishment, in 1899-1900, Froude's frictional coefficients, deduced from experiments with varnished wooden planes, were carefully checked as regards planes twenty feet long and 18 inches wide (6.1 m. x 0.457 m.). These also were varnished wooden planes, and the results were in substantial agreement with those of Froude. During the last few years, information has been published as regards the variation of resistance of models with variation of temperature in the model tank for the tank of the Messrs. Denny, at Dumbarton, Scotland, and for the William Froude tank at Kew, England. Sir Archibald Denny* stated that "the correction should be 4 per cent for 10 degrees Fahrenheit". In the same discussion, Mr. Baker† stated "With regard to skin friction correction, Sir Archibald Denny takes four per cent correction on the whole for a 10 degree change in temperature. We ourselves, correct 3 per cent for the same range of temperature but we only take our correction

* Page 63, Transactions of the Institution of Naval Architects, 1914.

† Page 64, Transactions of the Institution of Naval Architects, 1914.

on the skin friction, because so far as I can see, temperature cannot affect the wave resistance''.

In 1912 a special investigation of this matter was undertaken at the U. S. Model Basin, it being planned to run a model of a battleship and a model of a torpedo boat destroyer monthly, and note temperature upon each occasion. The models used at the U. S. Model Basin are of wood, varnished, and before a run, each model was smoothed by sandpapering and revarnished. The ordinary variation of temperature of the water in the U. S. Model Basin is from about 80 degrees in the height of summer to about 54 degrees in mid-winter. The temperature would fall much lower in the winter, except for the fact that the building is thoroughly heated in cold weather. In the winter of 1913, after filling the basin with fresh, cold water, the trial models were run in water as cold as 44.5 degrees. The results of these experiments were quite consistent. The only anomaly developed was when, after nine months, there had been such an accumulation of varnish that the varnish was scraped off and the models revarnished. This resulted in an anomalous reduced resistance of 3%. The results may be summarized as follows:

With change of water temperature, there was a perceptible change in the resistance of both the battleship and destroyer models. These changes in resistance, due to temperature, were apparently more closely related to the frictional resistance than to the residuary resistance, and the percentages given below are based on the frictional resistance alone. For the battleship model, the decrease in resistance for 10 degrees Fahrenheit increase in temperature was about 1.9 per cent of the frictional resistance, and for the destroyer model, 2.3 per cent of the frictional resistance.

It is seen that this variation is much less than that apparently occurring in Great Britain. The difference may be due to one or a number of different causes. The models used in the U. S. Model Basin are 20′ (6.1 m.) instead of 12′ to 14′ (3.66 to 4.27 m.) as usual in the British tanks; the models are wood, varnished, instead of paraffine; the average temperature in the Washington tank is materially higher than that of the British tanks; the water used, which is taken from the Wash-

ington City mains and has passed through sand filters, may be different in quality. Although the water used in filling the tank at intervals of from a few months to several years is taken direct from the Washington City mains, the small stream kept constantly running in is refiltered with a small amount of alum injected prior to refiltering.

It has been the endeavor of many people in the past to devise a formula expressing the resistance of a ship. The numerous results, of the model-basin experiments, which have been published in the last ten or fifteen years have been rather discouraging to the development of any such formula.

We have learned that a factor which is of importance at one speed is almost negligible at another. If we take two vessels, identical in dimensions and displacement, and build one with fine ends and the other with full ends, the fine-ended vessel will offer much less resistance over a certain range of speed, while at extreme speeds the full-ended vessel will be materially better.

Some years ago there were published the results of experiments with a large number of models at the U. S. Model Basin,* where proportions and coefficients had been varied systematically. The general results of this so-called standard series agree very closely with the general results from a very large number of additional models of usual types tried at the U. S. Model Basin, and also agree very well with exceptional results from other model basins. If a formula or formulae could be devised which would accurately express the plotted results of the standard series referred to, we should have the desideratum of many years. Attempts to do this have not been very successful, but the results, as plotted, show the broad features of the resistance of ships of usual types.

In the first place, the actual size of a vessel, its displacement, is, of course, the primary factor in its resistance. In the second place, the proportions come into play. Viewing this aspect of the case, the most important feature is the length used for a given displacement. Beam and draft are comparatively minor factors, while the length is a major factor. Length is of peculiar value for cutting down the wave-making

* "The Speed and Power of Ships", D. W. Taylor, 1910.

resistance; hence, we find that for fast vessels, where wave-making resistance is of such importance, the total resistance may nearly always be decreased by increasing the length. The third factor of primary importance is the longitudinal or prismatic coefficient, or what is in a way the same thing, the nature of the ends, whether fine or full. This is a very important factor. For speeds which are moderate in proportion to the length of the vessel, that is, when the speed-length ratio, or speed of vessel in knots divided by the square root of the length in feet is below about 0.8 (0.442 in metric units), the large midship section and fine ends are nearly always favorable to speed. About a speed-length ratio of 0.95 (0.525), there is a somewhat indeterminate region where variation of the longitudinal coefficient does not produce much effect. For high speeds, however, say of speed-length ratio above 1.25 (0.695), we gain, by reducing the midship section and using large longitudinal coefficients, even up to 66 per cent, and their associated full ends.

There appears no question that the fore body has much greater influence upon resistance than the after body. Experiments, described in the Transactions of the Society of Naval Architects,* show that radical variations in the shape of sections of the after body produced comparatively little effect upon resistance. The shape of the sections forward, however, does materially affect the resistance, and for the great majority of vessels there is no doubt that fine or hollow lines forward near the surface of the water, resulting in forward sections full below water, even bottle-shaped in many cases, are favorable to speed. Many sea-going people and naval architects are opposed to hollow water-lines forward, but there are indications that the results of model-tank experiments are making more and more impression upon practical people; and although we may not again find in fashion the very hollow lines of Scott Russell, we are certainly much nearer to this extreme than we were ten years ago.

Sir Archibald Denny, in his presidential address this year to the Institute of Marine Engineers, pointed out that of late

* "Some Experiments with Models having Radical Variations of After Sections", D. W. Taylor, Transactions of Society of Naval Architects and Marine Engineers, 1914.

years there has been a decided reduction in the block coefficients of low-speed cargo vessels, due to unsatisfactory experience at sea with those of coefficient of 0.80 or over. It would not have been necessary to settle this question by trial and error on full-sized ships at sea, if careful investigations of models had been carried out. There have now been published sufficient results of systematic model investigations* to enable the competent naval architect, dealing with merchant vessels, to settle with quite satisfactory accuracy the relative financial results to be expected in service from vessels of varying form and fullness of usual types. For special and unusual types and for vessels for high speed in shoal water, it is still necessary to go largely by guess work or to have recourse to model experiments, which will be found, by far, the most profitable capital investment in such cases.

PROPELLERS.

Since screw propellers came into common use, some 75 years ago, there have been innumerable theories of their action, and the screw propeller is still a favorite subject for the inventor. It is only within the last ten or fifteen years, however, since fairly extensive model-propeller investigations have been made public, that the fog—if I may so express it—surrounding propellers has begun to clear away. Even yet model experiments with propellers are not so generally accepted as those for ships. One outstanding result, however, of model-propeller investigations during the last few years is a demonstration of the fact that in former theories of propeller action an important factor has usually been overlooked. The vast majority of propellers have sections of the ogival type, with a straight driving face and the back an arc of a circle, or very close to that curve. In dealing with such propellers, the only factors usually considered have been diameter, pitch, and blade area,—the pitch being the uniform or average pitch of the driving face. Now, the diameter is really the primary factor affecting the action of a propeller.

* "Some Results of Model Experiments", R. E. Froude, Transactions of the Institution of Naval Architects, 1904. "The Speed and Power of Ships", by D. W. Taylor, 1910. "Model Experiments on the Resistance of Mercantile Ships' Forms", G. S. Baker, Transactions of the Institution of Naval Architects, 1914.

The pitch of the face is a convenient but purely conventional measure. We know, as a matter of fact, that an ordinary propeller, as described above, will develop a very material thrust when its slip, based upon the pitch of its face, is zero. In other words, with such a propeller the virtual pitch is always greater than the nominal or conventional pitch. The factor which has been ignored in this connection is the thickness of the blade, or, what amounts to the same thing, the shape of the back of the blade. The back of the blade has a very powerful influence on propeller action, and for the ordinary type of propeller described above, its shape is dependent upon the thickness of the blade. The amount of this influence was not at all realized until it was investigated by model experiments. For instance, published results of experiments at the U. S. Model Basin* show that two model propellers, each 16 inches (0.407 m.) in diameter, 19.2 inches (0.487 m.) face pitch, with a ratio of projected area to disk area of 0.3023, but differing in blade thickness, one being abnormally thin and the other abnormally thick, showed radically different results. Thus, at 5 knots speed of advance and 20% slip, the thin blade showed a thrust of 35 pounds (15.9 kg.), whereas the thick blade showed a thrust of 51 pounds (23.1 kg.), an increase of nearly 50%.

Blade area or surface is very unsatisfactory as a primary variable. This is essentially for the reason that the effect of variation of blade area depends upon how it is varied. In the case of a given propeller, if we increase blade area by increasing diameter, without materially changing the width of the blade, the effect is great. If we make the same increase of blade area by increasing the width of the blade, without increasing diameter, the effect is comparatively small; and if, as is apt to be the case in such instances, the increase of area is accompanied by a reduction of thickness, we may get no effect at all. For this reason, in any theory of propeller action, it is desirable to bring in the blade area in some manner which will make its effect always similar. Perhaps the most convenient method of doing this is to use, not the blade area, but the ratio of maximum or mean width of blade to the diameter. In this way, any change of blade area due to change of diameter is taken up by

* "The Speed and Power of Ships", by D. W. Taylor, 1910.

the diameter factor, and the change of area due to change of width is taken up by the width coefficient, or, as it is conveniently called, the mean-width ratio. In any reliable propeller theory, then, we must take account of the diameter and mean width of the blade, and the real pitch. In practice, the real or virtual pitch depends partly upon the nominal pitch of the face, and partly upon the blade thickness. It is convenient to separate these factors and use as variables the nominal pitch and what I have called the "blade thickness fraction", namely, the ratio between the root thickness of the blade at the axis (obtained by extending the straight lines of face and back to the shaft center), and the diameter of the propeller. If we adopt these variables, it is possible, by semi-empiric methods, to express the results of any systematic series of propeller experiments by formulae. Of course, the results of such experiments must first be expressed graphically, and, for practical purposes, complete graphic expressions are as good as formulae; but most people seem to prefer to work out a result by means of a formula rather than from graphic data.

Some years ago* there were published the results of experiments, at the U. S. Model Basin, with 120 different model propellers, varying in pitch and mean width ratio and blade thickness. These were three-bladed propellers, the blades being elliptical. Careful analysis of the results of these experiments shows that they may be expressed with close approximation by formulae, which, though somewhat complicated, are not too inconvenient for use.

Let P denote the horsepower being absorbed by the propeller.

Let T denote the thrust of the propeller in pounds. (Kilograms in metric system.)

Let V denote speed of advance of the propeller (not the ship) through the water, in knots.

Let d denote diameter of propeller in feet. (Meters in metric system.)

Let p denote pitch in feet of the driving face. (Meters in metric system.)

Let a denote pitch ratio or $p \div d$.

Let w denote mean-width ratio or (mean width of blade $\div d$).

* "Speed and Power of Ships", by D. W. Taylor, 1910.

Let t denote blade-thickness fraction, or (thickness of radial blade section at axis if lines of face and back are extended) $\div$ diameter.

Let R denote revolutions per minute.

Then

$$\text{Slip, } s, = \frac{pR - 101\frac{1}{3}V}{pR}$$

In metric units,

$$s = \frac{pR - 30.9V}{pR}$$

For blade widths and thicknesses and working slips found in practice, we have for elliptical three-bladed propellers, with blades of ogival section, advancing through undisturbed water

$$T = \frac{d^2V^2}{(1-s)^2} \times \frac{s + \frac{.057}{w} - .0785 + a\left(.015 - \frac{.0175}{w}\right) + \left\{2.54 - 32\,(w - .15)^2\right\}t}{.2 + (a - .5)\,\frac{9.8 - 16\,w}{9}}$$

In metric units,

$$T = 4.883\,\frac{d^2V^2}{(1-s)^2} \times \frac{s + \frac{.057}{w} - .0785 + a\left(.015 - \frac{.0175}{w}\right) + \left\{2.54 - 32\,(w - .15)^2\right\}t}{.2 + (a - .5)\,\frac{9.8 - 16\,w}{9}}$$

For working slips, say, between $s = 0.2$ and $s = 0.35$ and for values of w between, say, 0.25 and 0.40, this formula represents almost exactly the results of the model-propeller experiments at the U. S. Model Basin. While not quite so close, the agreement with a series of experiments made by Mr. R. E. Froude* with elliptical propellers is quite close enough for practical purposes. While the formula includes the mean-width ratio, w, the influence of this factor is comparatively small. Thus in Froude's experiments, above referred to, an increase of some 10 per cent in mean width, other circumstances being unchanged, results in an increase of only about 1 per cent in thrust.

* "Results of Further Model Screw Propeller Experiments", Transactions of the Institution of Naval Architects, 1908.

While this semi-empirical formula applies strictly to elliptical blades, the shape may depart materially from the elliptical and the formula will still apply fairly well. Fig. 1 shows, contrasted with an elliptical blade, an extremely wide-tipped blade of the same area experimented with by Froude. The thrust from the wide-tipped blade is only some seven or eight per cent greater than that given by the formula for the elliptical blade.

OUTLINES OF ELLIPTICAL AND WIDE-TIP
PROPELLER BLADES HAVING THE SAME DEV
ELOPED AREA AND MEAN WIDTH RATIO.

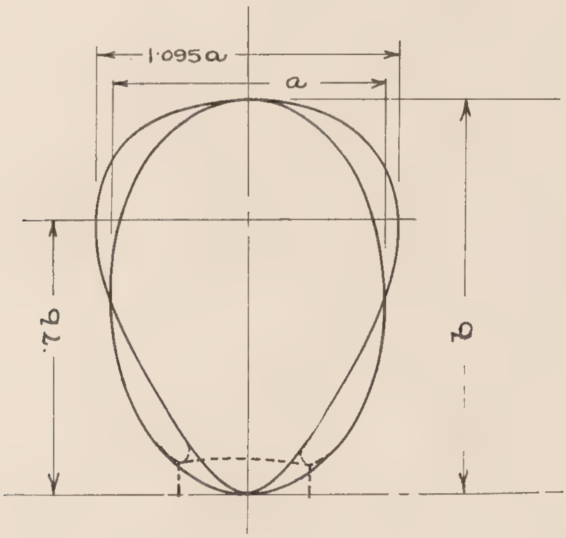


Fig. 1.

When we undertake to devise a semi-empirical formula for the power absorbed by an elliptical-bladed propeller, it is found that variation of blade width affects it so little that, for practical purposes, we need not consider w in the formula for power, which is

$$P = \frac{0.88 + \frac{0.69}{a} + \left(1.3 + \frac{10.3}{a}\right)t}{1 - s} \left(\frac{pR}{1000}\right)^3 \frac{d^3}{p}$$

We may write this

$$\frac{P(1-s)}{\left(\frac{R}{100}\right)^3} = \left\{0.88 + \frac{0.69}{a} + \left(1.3 + \frac{10.3}{a}\right)t\right\} \frac{d^3p^2}{1000} = C, \text{ say}$$

In metric units

$$\frac{P(1-s)}{\left(\frac{R}{100}\right)^3} = \left\{0.88 + \frac{0.69}{a} + \left(1.3 + \frac{10.3}{a}\right)t\right\} 0.380\, d^3 p^2 = C$$

Where C is constant and known for a given propeller.

Derived from this, the equation,

$$1 - s = \frac{C}{P}\left(\frac{R}{100}\right)^3$$

will be found very useful for approximating the real slip, as contrasted with the apparent slip, when analyzing trial results.

Examination and consideration of the above formulae and of the experimental results which they represent show, as to be expected, that for cases as found in practice the slip is the main factor and the variation of slip incident to a permissible variation of revolutions for a given power will over-shadow the effect of usual variation of blade width and thickness.

For a final approximation, then, for design purposes, the experimental results give the following for three-bladed propellers with elliptical blades, mean-width ratio from 0.25 to 0.40 and blade-thickness fractions such as are found in practice.

For best efficiency

$$d = \frac{(PV)^{\frac{1}{6}}}{R^{\frac{2}{3}}}\left(63.5 - 50\,\frac{V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}\right)$$

In metric units,

$$d = \frac{(PV)^{\frac{1}{6}}}{R^{\frac{2}{3}}}\left(19.1 - 15.3\,\frac{V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}\right)$$

$$\text{Pitch ratio, } a = 0.74 + 3.3\,\frac{V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}$$

$$\text{Efficiency} \quad = 0.768 - 0.01\,\frac{RP^{\frac{1}{2}}}{V^{\frac{5}{2}}}$$

For propellers with smaller diameter and working with .025 less efficiency

$$d = \frac{(PV)^{\frac{1}{6}}}{R^{\frac{2}{3}}}\left(57 - \frac{50\,V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}\right)$$

In metric units,

$$d = \frac{(PV)^{\frac{1}{6}}}{R^{\frac{2}{3}}}\left(17.4 - \frac{15.3\,V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}\right)$$

$$\text{Pitch ratio, } a = 1.08 + \frac{3.3\,V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}$$

$$\text{Efficiency} \quad = .743 - .01\,\frac{RP^{\frac{1}{2}}}{V^{\frac{5}{2}}}$$

For propellers with larger diameter and working with .025 less efficiency

$$d = \frac{(PV)^{\frac{1}{6}}}{R^{\frac{2}{3}}}\left(70 - \frac{50\,V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}\right)$$

In metric units,

$$d = \frac{(PV)^{\frac{1}{6}}}{R^{\frac{2}{3}}}\left(21.3 - \frac{15.3\,V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}\right)$$

$$\text{Pitch ratio, } a = .52 + \frac{3.3\,V^{\frac{5}{2}}}{RP^{\frac{1}{2}}}$$

$$\text{Efficiency} \quad = .743 - .01\,\frac{RP^{\frac{1}{2}}}{V^{\frac{5}{2}}}$$

For four-bladed propellers, with close approximation the diameter, pitch and efficiency are, respectively, 0.94, 0.98, and 0.96 of those for three-bladed propellers; while for two-bladed propellers, they are 1.035, 1.01 and 1.02.

The preceding formulae assume that the law of comparison applies fully and that the speed of advance, V, of the propeller through the water is known. If the law of comparison did apply to all cases, with the data which have now become accumulated from model-propeller experiments, the propeller problem would, in practically all cases, be capable of a solution in advance sufficiently close for practical purposes, if not of scientific accuracy. As a matter of fact, the law of comparison does apply with close approximation to the majority of practical cases. For the propeller, however, as for the ship, in order that the law may apply exactly, the pressures should be in the same ratio as the dimensions. This, of course, is not the case. The model propeller is tested under a head of, perhaps, 1 ft. (0.3 m.), due to submergence, and 34 ft. (10.4 m.), equivalent to the atmospheric pressure. The full-sized propeller operates with submergence in proportion to its size, but the head due to atmospheric pressure is the same for the full-sized propeller as for the model. Hence, we find that with some full-sized propellers, particularly the high-speed type, the now well-known phenomenon called "cavitation" occurs, while there is no indication of it with the models of such propellers. Since Barnaby first described cavitation,* as observed in the trials of the "Daring" many years ago, there has been

* "The Formation of Cavities in Water by Screw Propellers at High Speed", Sydney W. Barnaby, Transactions of the Institution of Naval Architects, 1897.

much study and thought given to it, but the only process, in practice, which has been generally satisfactory in reducing or avoiding it is increase in blade area and reduction of the thickness of the blades (particularly at the leading edge) to the limit permissible by practical considerations.

The many endeavors to devise a form of blade section of moderate width which the water will continue to hug when the speed of the blade through the water is extreme, have not heretofore been strikingly successful. It is possible that they may show some success in the future, enabling the propeller designer to adopt a type of blade somewhat more efficient than the very wide blade, whose friction is apt to be excessive. Even so, the gain would not be very great, as the loss of efficiency due to the broad blade is not very serious.

Attempts accurately to define the region where cavitation is to be expected have not, hitherto, been very successful. The limiting thrust per unit of projected area originally proposed by Barnaby has been materially exceeded in some cases without cavitation, while in other cases cavitation has been found with much lower thrusts. The same statements virtually apply to tip speed, which is, perhaps, a somewhat better criterion. Here, again, the shape of the blade section is a matter of primary importance. For a given type of blade section, we may adopt either tip speed or thrust as a criterion, with fairly satisfactory results, provided we do not go beyond the limits which have been found satisfactory for the same type of blade in other cases.

Attempts have been made to investigate cavitation with models. Sir C. A. Parsons has made experiments along this line with hot water, or in a partial vacuum. The idea, in each case, was to reduce the pressure around the model in proportion to its size. Little or nothing of value in defining the field of, or in avoiding, cavitation, has been published as a result of these experiments.

The formulae given, derived from model experiments, assume, as already stated, that V, the speed of advance through the water, is known. When we come to apply the propeller at the stern of the ship, we do not know, as a rule, the speed of advance through the water. The propeller acts in the wake of the ship and in most cases the wake is positive, which means that

the speed of advance of the propeller through the disturbed water in which it works is less than the speed of the ship. Model-experiment investigations have been made by R. E. Froude,* and, notably, by W. J. Luke,† of late years, using a model propeller behind the model of the ship. This method enables not only the wake but the thrust deduction, or suction of the propeller upon the stern of the ship, to be investigated. From Luke's results we may roughly express the wake as follows:

Let k denote the actual wake fraction, the virtual uniform following current in which the propeller acts being equal to kV, where V is the speed of the ship. Let b denote block coefficient. Then for single screws $k = 0.05 + 0.5b$. For twin screws $k = 0.2 + 0.55b$. These are very rough approximations, as reference to Luke's papers will show that the wake varies with the position of the screws and also with their direction of rotation. The wake means a gain in efficiency; whereas the thrust deduction means, of course, a loss as compared with the case where the propeller is driving what R. E. Froude has happily called a "phantom ship", namely, a ship which offers the resistance of the actual ship but does not disturb the water. It is usually assumed that the wake gain and thrust deduction virtually offset each other as regards efficiency. This is, actually, not exactly the case, and this whole matter of wake factor and thrust deduction is one needing a thorough clearing up. The assumption that the wake is uniform is, of course, simply a working hypothesis for convenience, the actual wake being far from uniform. This was demonstrated many years ago in some experiments made by Mr. George A. Calvert.‡ Experiments recently made at the U. S. Model Basin, with special apparatus, throw additional light upon this matter.

* "A Description of the Method of Investigation of Screw Propeller Efficiency", Transactions of the Institution of Naval Architects, 1883. "The Determination of the Most Suitable Dimensions for Screw Propellers", Transactions of the Institution of Naval Architects, 1886.

† "Experimental Investigations of Wake and Thrust Deduction Values", Transactions of the Institution of Naval Architects, 1910. "Further Experiments on Wake and Thrust Deduction", Transactions of the Institution of Naval Architects, 1914.

‡ "On the Measurement of Wake Currents", Transactions of the Institution of Naval Architects, 1893.

When fluid is flowing past a sphere, or a sphere is advancing into still water, the excess pressure on the sphere (above that due to its submergence) immediately around the axis of advance is equivalent to the velocity head of advance, and the pressure at ninety degrees from the axis of advance is below the natural pressure due to submergence. Around some circle between the two, the pressure in the moving water around the sphere will be the same as the pressure in the undisturbed water at the same depth below the surface. In theory, this circle is 41° 49′ away

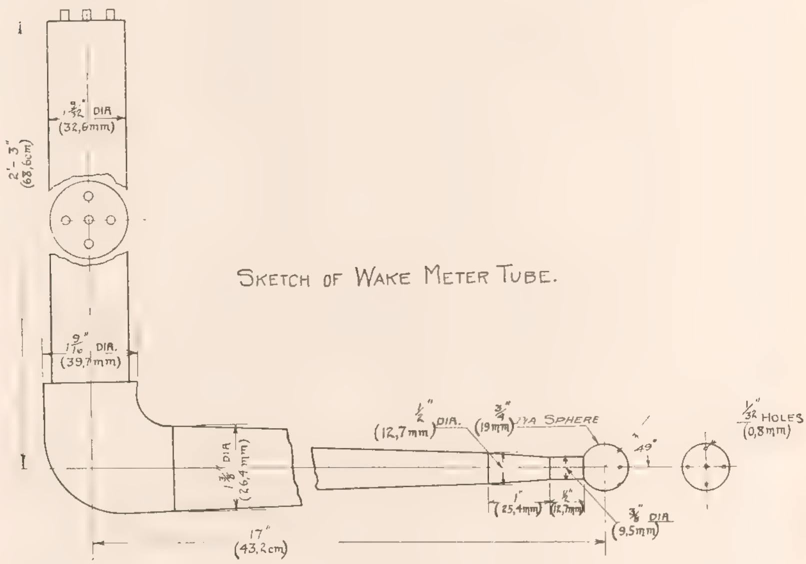


Fig. 2.

from the axis. As a matter of fact, careful experiments with a ¾-in. (19 mm.) sphere showed that, due to friction or some other cause, the actual distance from the axis was almost exactly 49°. A ¾-in. (19 mm.) sphere, Fig. 2, was made with five holes 1/32 in. (0.8 mm.) in diameter, one in the axis, two on a horizontal line 49° away from the axis, and two on a vertical line 49° away from the axis. Each hole was connected with a vertical glass tube showing head and change of head. The sphere was on the end of a horizontal arm, which was carried, in turn, by a vertical tube sufficiently far away not to affect the motion around the sphere. The apparatus was calibrated from the Model Basin

carriage, by advancing it with the axis of the tube or the central hole at various angles from both the vertical and horizontal. It was found that the difference between pressure head measured at the center hole and the average head of the other holes indicated the speed with great accuracy, and the differences of head shown in the tubes connected with the other holes enabled the angle of advance to be determined accurately, the error being no greater than a fraction of a degree. It was also found that this sphere could be placed so that its center would be within one and a half inches or so of a plane without the motion around it being materially affected, and, when placed closer, the variation from normal conditions could be calibrated. The sphere then being placed in any position near the stern of a model, whose speed through the water is known, and readings taken of the heights of water in the tubes connected with the various holes, we can determine the actual speed and direction of flow of the water.

Fig. 3 shows for the model of Fig. 17 the directions with reference to the axis of the vessel under way and the amounts of the wake currents at the points indicated. Since friction is relatively greater in a model than in a full-sized vessel, the amounts and directions of the wake of a full-sized vessel would differ slightly from those around the model, but it is not likely that the difference would be material.

Section B would be a fairly usual location for the propeller of this vessel, the circle indicating a propeller of 8 ft. diameter for the full-sized vessel. It is seen, then, that the blades of such a propeller encounter most variable conditions during a revolution, the axial or fore and aft velocity of the wake varying from 4 to 23 per cent. These axial velocities are for a vessel which has fine lines aft; for a full vessel, the wakes would be greater and the variations greater. It would seem evident that when the propeller must work under the conditions indicated by Fig. 3, fine-spun theories as to angles of slip, etc., in still water, are quite irrelevant as regards actual conditions. Incidentally, it may be remarked that the wakes indicated at distances from the hull, where the frictional wake would have little or no effect, agree very well in a general way with what would be expected from theoretical considerations of stream-line flow.

Some recent experience with U. S. vessels has emphasized the desirability of having strut arms parallel to the lines of natural flow of the water, and the apparatus referred to enables the proper angles to be readily determined. Sometimes these are far from what we would make them, if evolved from our inner consciousness.

ROLLING.

The matter of rolling is thrust upon the attention of all who have to do with ships. Of late years there has been a recrudescence of interest in this important subject, and the investigations made of it, instead of being of academic interest only, as had mainly been the case formerly, are of great practical interest and value. Model experiments have been resorted to in the case of Russo's Navipendulum* and with the apparatus devised originally by Biles.† Schlick‡ some years ago and Sperry§ more recently have actually checked rolling by gyroscopes, and Frahm** water tanks for the same purpose have recently been brought forward and installed in a number of vessels.

Those who investigate the literature on the subject will find little or nothing of practical value before the wonderful paper contributed by William Froude to the Institution of Naval Architects in 1861.†† In this paper Froude laid down the underlying principles affecting rolling, particularly unresisted rolling, and

* "An Experimental Method of Ascertaining the Rolling of Ships on Waves", Captain G. Russo, Transactions of the Institution of Naval Architects, 1900.

† "Experimental Determination of the Effect of Internal Loose Water upon the Rolling of a Ship amongst a Regular Series of Waves", A. Cannon, Transactions of the Institution of Naval Architects, 1913, Part II.

‡ "Experiments with Dr. Schlick's Gyroscopic Apparatus for Steadying Ships", Sir Wm. H. White, Transactions of the Institution of Naval Architects, 1907.

§ "Active Type of Stabilizing Gyro", E. A. Sperry, Transactions of the Society of Naval Architects and Marine Engineers, 1912.

** "Neuartige Schlingertanks zur Abdampfung von Schiffsrollbewegungen und ihre erfolgreiche Anwendung in der Praxis", H. Frahm, Jahrbuch der Schiffbautechnischen Gesellschaft, 1911.

†† "The Rolling of Ships", William Froude, Transactions of the Institution of Naval Architects, 1861.

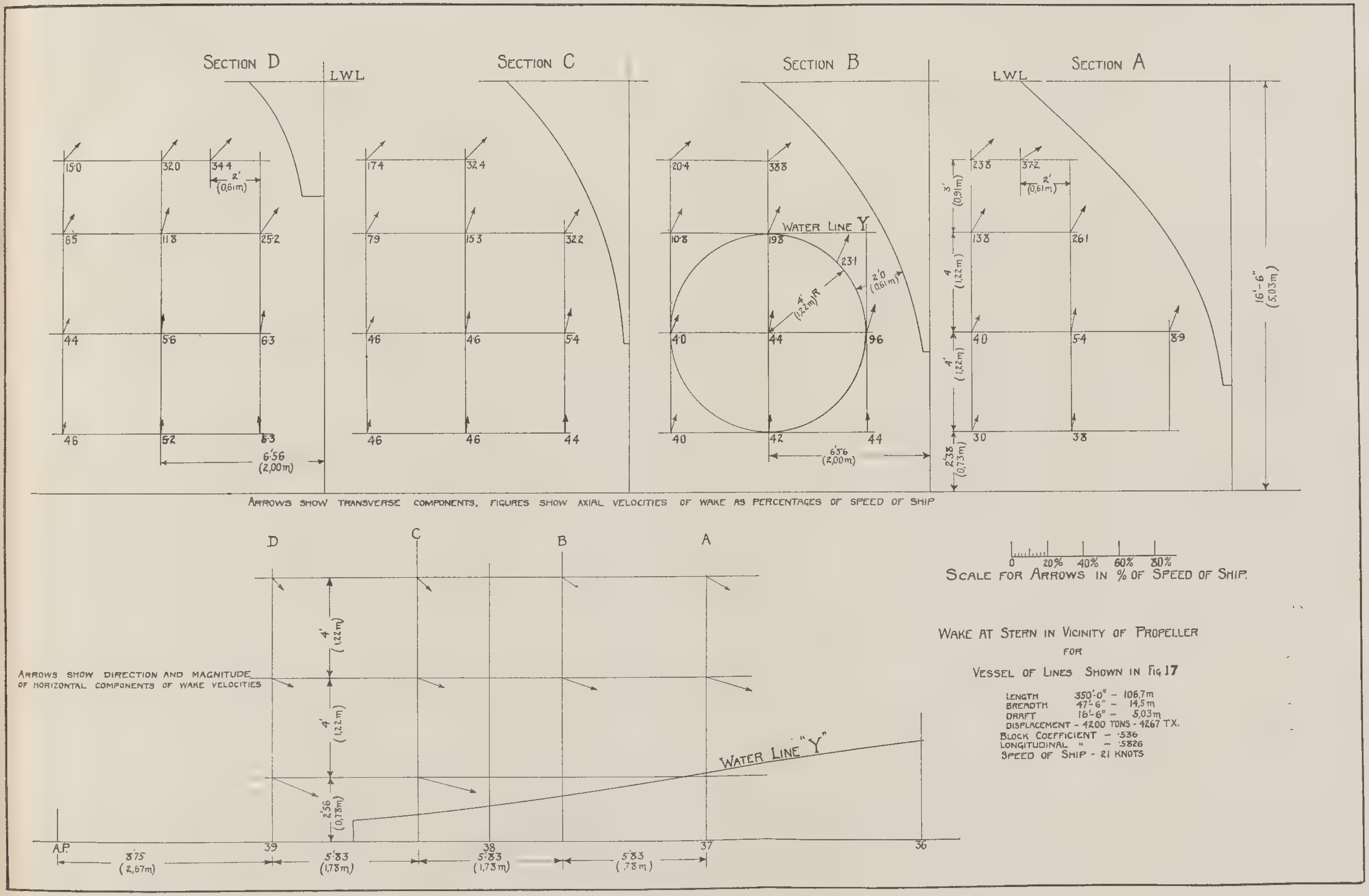

SECTION D
SECTION C
SECTION B
SECTION A
LWL
WATER LINE Y
ARROWS SHOW TRANSVERSE COMPONENTS, FIGURES SHOW AXIAL VELOCITIES OF WAKE AS PERCENTAGES OF SPEED OF SHIP
ARROWS SHOW DIRECTION AND MAGNITUDE OF HORIZONTAL COMPONENTS OF WAKE VELOCITIES
WATER LINE "Y"
SCALE FOR ARROWS IN % OF SPEED OF SHIP.
WAKE AT STERN IN VICINITY OF PROPELLER
FOR
VESSEL OF LINES SHOWN IN FIG 17
LENGTH 350'-0" - 106,7m
BREADTH 47'-6" - 14,5m
DRAFT 16'-6" - 5,03m
DISPLACEMENT - 4200 TONS - 4267 TX.
BLOCK COEFFICIENT - ·536
LONGITUDINAL " - ·5826
SPEED OF SHIP - 21 KNOTS

Fig. 3.

although there were soon other workers in this field, it may be said that the theory of rolling, as accepted today, is practically the theory developed by William Froude in his paper of 1861, and in his later writings on the subject. Perhaps the most important practical result of Froude's early work was the demonstration of the fact that if we wish to reduce rolling, particularly in large ships, we should reduce the metacentric height and lengthen the period of the ship. Formerly it had been generally thought that the greater the stability the less the rolling. Froude assumed at first that a ship broadside to regular waves of uniform period tended, at any instant, to set herself perpendicular to the disturbed water surface, and that the amount of this tendency was measured by the angle between the actual position of the mast of the ship and the normal to the wave surface. Subsequently, he substituted for the wave surface what he called the "effective" wave surface, which he took to be the surface of equal pressure passing through the center of buoyancy of the ship. The voluminous work of Froude and his successors on the theory of rolling in the trough of a wave may almost be summarized in a single equation, which is a modified form of an equation given by Lloyd Woollard, Esq.,* in a paper before the summer meeting of the Institution of Naval Architects in 1913.

Let θ denote the angle of inclination of the vessel at any time, t, measured in seconds from an arbitrary time of starting, or zero of time. Let P denote the natural period of unresisted rolling of the ship in still water, which is expressed with close approximation by the formula $P = \dfrac{2\pi\rho}{\sqrt{gm}}$, where ρ is the radius of gyration of the vessel about its center of gravity, m is the metacentric height and g is the acceleration due to gravity. P is the complete or cyclic period of the double roll. Let P_w denote the natural period of the wave. Let e be the base of hyperbolic logarithms. Let α be the maximum slope of the wave affecting the ship—not the surface slope, but the virtual slope. Let C be the coefficient of resistance to rolling of the ship, the resistance being assumed to vary as the first power of the angular

* "The Effect of Water Chambers on the Rolling of Ships", Lloyd Woollard, Transactions of the Institution of Naval Architects, 1913, Part II.

velocity, and let B and β be arbitrary coefficients depending upon the initial circumstances of motion. Then we have

$$\theta = Be^{-C\frac{2\pi t}{P}} \sin\left\{\frac{2\pi t}{P}\sqrt{1-C^2}+\beta\right\}$$
$$+\alpha\frac{P_w{}^2}{\sqrt{(P^2-P_w{}^2)^2+4\,C^2\,P^2\,P_w{}^2}}\sin\left(\frac{2\,\pi\,t}{P_w}-\tan^{-1}\frac{2\,C\,P\,P_w}{P_w{}^2-P^2}\right)$$

When $\alpha = O$ and C has a value, or there is resistance to rolling, we have the case of resisted rolling in still water, which, as is obvious from the equation, is soon extinguished. When α has a value and $C = O$, the rolling is unresisted in uniform waves. In this case $e^{-C\frac{2\pi t}{P}}$ is equal to unity and θ is the result of two superposed rolls, one a free roll, so-called, of maximum amplitude, B, and period P, and the other a forced roll of maximum amplitude $\alpha\frac{P_w{}^2}{P^2-P_w{}^2}$ and period P_w, or the period of the wave.

In practice, C is quite small, but not negligible, so we would expect to find a ship in the trough of the sea soon rolling in the period of the wave, as prescribed by the second term. The formula was deduced upon the assumption that resistance to rolling varies as the first power of the angular velocity of rolling. While this assumption may be justified, if we properly choose C and deal with small rolling only, it is far from being exact. More than forty years ago there was an extended discussion on this question between Mr. William Froude and M. Emile Bertin, in "Naval Science" and elsewhere. Mr. Froude maintained that resistance to rolling was properly expressed by two terms, one, the more important, varying as the first power, and the other as the square of the angular velocity of rolling. M. Bertin stoutly maintained then, and to this day, that resistance to rolling should vary as the square of the angular velocity. I will give later results of some model investigations in this connection, but perhaps for the reason that C is small compared with the other quantities involved, the above expression for forced roll, regardless of the original assumption involved, is undoubtedly practically exact under the circumstances assumed, of uniformity of sea and known effective slope.

If we take a pendulum mounted so as to have resistance to oscillation and give it harmonic impulses of a period different

from its natural period, and of strength corresponding to an angle α in the formula, the pendulum very soon sets up forced oscillations of the period of the impulses, and until the resistance to the motion of the pendulum is relatively much greater than the resistance to rolling of a ship, the amplitude of these uniform forced oscillations will be almost exactly that derived from the formula above.

The formula has also been checked as to period by a number of experiments with models in uniform waves at the U. S. Model Basin. It is remarkable how models, whether with or without bilge keels, when in the trough of a series of uniform waves, will promptly fall into step and oscillate in consonance with waves whose periods vary from ¼ to 1½ times the natural period of the model. That there is a practical limit to this, however, is indicated by model experiments. For instance, a wave whose period is only from ¼ to ½ the natural period of the ship will not induce forced rolling in the latter unless it has a certain height. Waves that are low as well as short have little or no effect, as might be expected.

Since experiment confirms so fully the formula above, it might seem at first sight that it is, in theory, a complete solution of rolling problems. As a matter of fact, it is far from this, for the simple reason that it assumes uniform isochronous known impulses from the waves. While the sea has infinite variety and will at times give uniform isochronous impulses, this is a rare occurrence. In an ordinary sea, successive waves vary materially in height and period. The net result is that the free-rolling term in the formula does not disappear. We may express this result in *quasi* mathematical fashion by saying that instead of measuring t from one initial condition, we are constantly taking a fresh start, and that with each fresh start, B, β, α and P_w are changed in an unknown manner to suit the new initial conditions.

Fig. 4 is an actual rolling record from a large battleship in a rough sea and is fairly typical of the usual rolling of a large ship. The irregularity of the rolling is obvious upon inspection. We note in Fig. 4, as the most conspicuous feature, that periods of maximum rolling alternate with periods of comparative quiescence. This is typical of theoretical, unresisted rolling in a series of waves whose period differs from the period of the

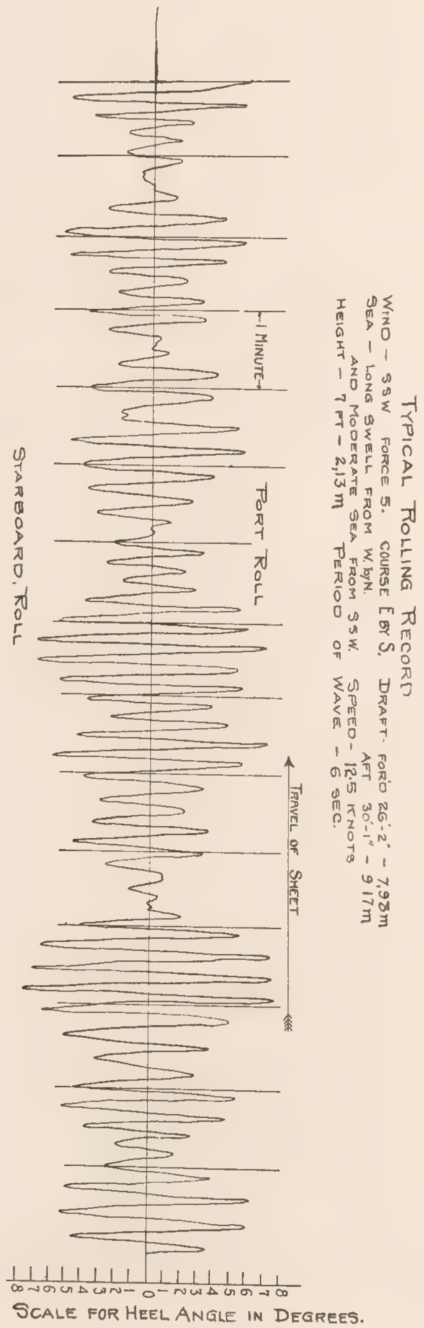

TYPICAL ROLLING RECORD
WIND – SSW FORCE 5. COURSE E BY S. DRAFT. FORD 26'-2" – 7,98m
AFT 30'-1" – 9,17m
SEA – LONG SWELL FROM W. by N. AND MODERATE SEA FROM SSW. SPEED – 12·5 KNOTS
HEIGHT – 7 FT – 2,13 m PERIOD OF WAVE – 6 SEC.
←1 MINUTE→
PORT ROLL
STARBOARD ROLL
TRAVEL OF SHEET
8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8
SCALE FOR HEEL ANGLE IN DEGREES.

Fig. 4.

ship, but, in the latter case, the alternations as shown by the formula are systematic and regular, while in actual rolling they are neither. If we could estimate accurately the forced rolling of a given ship in a given uniform sea, we could be certain that the maximum angle of actual roll would not be as much as twice the angle of forced roll. For if we had the ship in step with the sea and doing forced rolling, the worst that could happen would be for the phase of the sea to suddenly shift, so that the forced roll became a free roll and a new forced roll of the same amount would grow up, being superposed upon the decreasing free roll. Evidently the combination of the decreasing free roll and increasing forced roll could never exceed twice the maximum forced roll.

Unfortunately, as to one of the most important factors in the forced-rolling term—namely, α—we have very little real knowledge. Froude started with the natural assumption that α was the maximum surface slope of the wave. He soon found, however, that, in practice, ships and models did not roll so much as would follow from this assumption, and consequently took for α the maximum slope of the surface of equal pressure at the depth of the center of buoyancy below the surface. There are some indications in Froude's latest writings on this subject that he regards even this reduced value of α as perhaps too large. The matter is one of much practical importance for several reasons:

1. Heavy rolling of ships is always mainly forced rolling. When there is approximate synchronism of the wave impulses with the natural period of the ship, she approaches rapidly the maximum forced roll, which, neglecting resistance, is $\alpha \frac{P_w^2}{P^2 - P_w^2}$. The greater the natural value of α the more rapidly the roll grows, and the greater the range of wave period over which dangerous rolling may be set up.

2. In practice, when there is approximate synchronism, ships would promptly capsize in a regular sea, were it not for the fact that the natural increment of roll due to the passage of a wave is neutralized by the natural decrement of roll due to the resistance of the ship to rolling while the wave passes. The greater the value of α the greater the rolling angle to produce an equal decrement.

3. When one undertakes to stop rolling by a gyroscopic or other mechanical device, it is very desirable to know how much roll a given wave will communicate to a given ship. Only when this is known do we know how much of a sea we have provided against with our apparatus.

It might seem, at first sight, as if observations of rolling on actual ships would give the information desired. While extensive observations of this nature would be of much help (they seem very difficult to obtain and are painfully rare), they would not fully meet the need, for the reason that increment of roll due to the passage of a given wave might, in the case of a rolling ship, be very much greater or very much less than if the ship had been originally upright at rest. It is the increment in the latter condition that we need to know in connection with apparatus to hold the ship upright.

Some investigations, at the U. S. Model Basin, of the rolling of models, while not conclusive, indicate strongly the need for developing the theory of rolling beyond the condition in which it was left by Froude. Such model investigations are by no means easy. One great difficulty is in connection with the waves. It is, of course, easy to produce waves of uniform length, but waves advancing in a canal of limited width, although looking very uniform to the eye, when carefully investigated seem to vary in height in a very puzzling fashion. The model experiments referred to seem to indicate that not only the metacentric height but the absolute height of the center of gravity influenced the rolling behavior.

This is, upon consideration, just what might be expected. Consider a ship in the trough of the sea. She is acted upon by the reactions of the water, which may be regarded as an infinite number of transverse forces. These can be reduced to a single resultant, and we know from the elementary principles of mechanics that the center of gravity will move as if the resultant were exerted through it, while there will be a movement of rotation due to the leverage of the resultant about the center of gravity. This is altogether independent of any question of metacentric height. We know, as a matter of fact, that under such circumstances the center of gravity of the ship has an orbital motion. Fig. 5 gives actual paths of the center of grav-

ity of a model 20 ft. 0 in. x 3.436 ft. x 0.970 ft. x 2500 lbs. (6.1 m. x 1.05 m. x 0.296 m. x 1134 kg.) displacement in waves of the length and height indicated. These orbits are elliptical, probably because the waves are of the shallow-water type when the water particles traverse elliptical orbits. For deep-water waves the orbits would have been nearly circular. From the orbital path, it would be possible to deduce the acceleration at any point and, hence, the corresponding forces. Also, if the angular motion were carefully determined, we could, by analysis, deduce the positions or lines of action of the resultant forces. While experiments hitherto made are not of such order of accuracy as to allow this to be done, it may be pointed out that the orbital path of the center of gravity in deep-water waves is roughly circular, indicating that the actual resultant unbalanced forces are harmonic in their nature. If we take a vessel at the steepest part of the wave, when she is moving vertically in her orbit, the acceleration of the center of gravity is horizontal, so that if the ship is vertical at the instant, the resultant force acting upon her is horizontal.

If this resultant force should pass below the center of gravity, instead of above, the ship would actually tend to roll toward the wave instead of away from it. In practice it would seem that for most ships the resultant is not far from the metacenter. Froude's theory seems virtually to assume that the resultant passes always through the metacenter. It is quite possible, however, that, particularly when the ship is specially shaped with this in view, the resultant will really pass below the metacenter. This would account for the fact that reduction in metacentric height appears often to reduce rolling more than can be accounted for by the change in metacentric height alone.

It is not likely that the actual wave forces upon a ship have a single point through which they pass. The resultant force will cut the axis at varying distances above the center of gravity as a wave passes, and there will also be variations in this respect as the waves vary and as the ship rolls. But it is obvious that the closer to the center of gravity the line of the resultant force due to a wave, the less the rolling, and that this fact should not be ignored in shaping vessels.

In Fig. 5 we see that as the metacentric height of the model

is reduced from 0.35 ft. to 0.05 ft. (.107 m. to .015 m.), the rolling is markedly reduced, the model in the latter case remaining practically upright, though the center of gravity describes an elliptical path which shows a considerable bodily motion of the model. In this case it appears that the resultant of the external forces acted very close to the center of gravity and the metacenter.

The diagram for the 0.15-ft. (.046 m.) metacentric height refers to a somewhat disquieting occurrence. The natural period of the ship was about twice that of the wave, and there is rather heavy rolling in the natural period. Large ships are much more likely to encounter steep waves of half their period than of their full period, and if half period waves can produce rolling effects similar to those of synchronous waves, dangerous rolling is apt to be caused by them. But even with the accurate adjustment possible with artificial waves, this heavy rolling from half period waves was not easily produced; so with the nearly always irregular waves of the sea, the danger of heavy rolling from half period waves is probably remote. Still it exists.

I have referred already to the difference of opinion between Mr. Froude and M. Bertin as to the power of the angular velocity with which the resistance of the ship to rolling in still water varies. For such rolling a large number of accurate declining-angle curves of models have been obtained at the U. S. Model Basin, usually from an angle of 15 degrees or so; and these have been analyzed, the detailed methods being given in Appendix II. It was found that the nature of these declining-angle curves was such that they did not satisfactorily agree with either Froude's theory or Bertin's theory. Any particular curve could, however, be represented quite well, and many of them almost exactly, on the assumption that the resistance to rolling at any instant varied as a coefficient into some fractional power of the angular velocity. Unfortunately, this fractional power varied somewhat inconsistently, although in many cases it seems to be very close to 1.5. The limits, however, appear to be fairly well defined. In no case tested did the resistance to rolling vary as a power of the angular velocity greater than 2 or less than 1. When rolling in still water, the center about which the ship revolves is, in practically every case, between the center of gravity and the water-line; that is, when the center of gravity is below

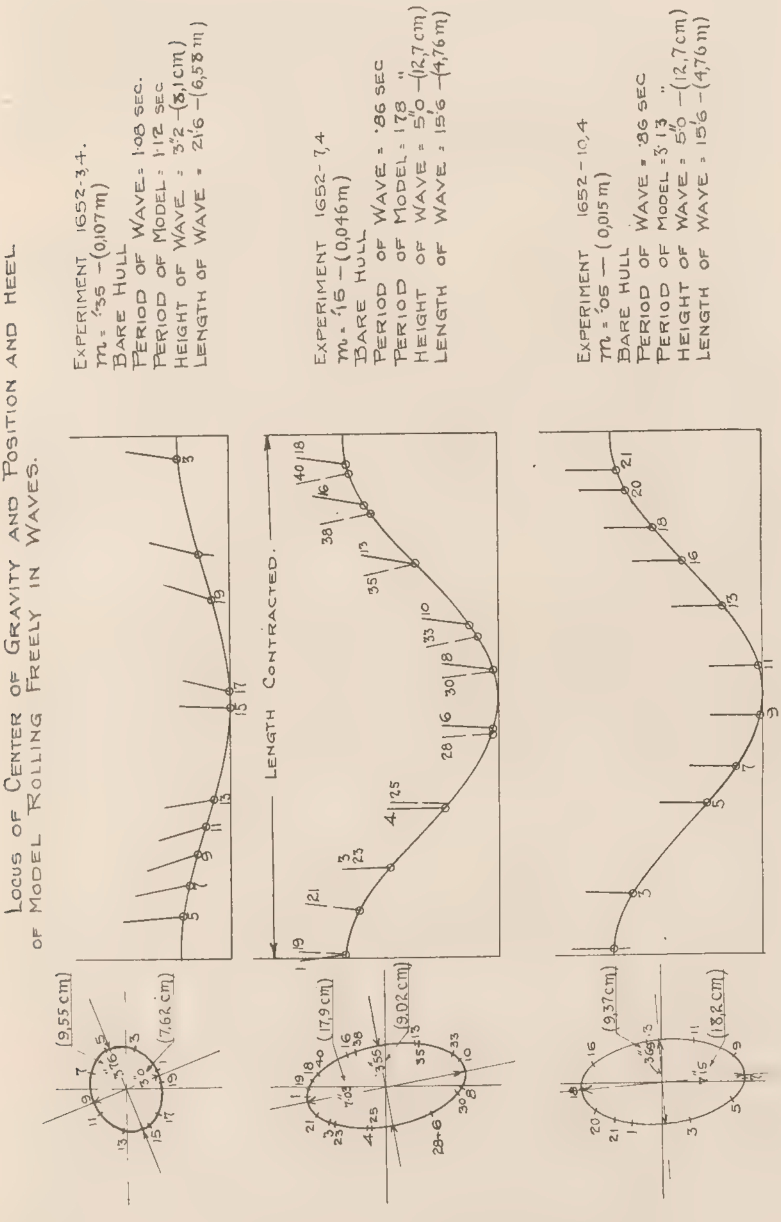

LOCUS OF CENTER OF GRAVITY AND POSITION AND HEEL
OF MODEL ROLLING FREELY IN WAVES.
EXPERIMENT 1652-3,4.
m = '35 — (0,107 m)
BARE HULL
PERIOD OF WAVE = 1·08 SEC.
PERIOD OF MODEL : 1·12 SEC
HEIGHT OF WAVE : 3"2 — (8,1 cm)
LENGTH OF WAVE = 21'6 — (6,58 m)
EXPERIMENT 1652 - 7,4
m = '15 — (0,046 m)
BARE HULL
PERIOD OF WAVE = '86 SEC
PERIOD OF MODEL : 1'78 "
HEIGHT OF WAVE = 5"0 — (12,7 cm)
LENGTH OF WAVE : 15'6 — (4,76 m)
EXPERIMENT 1652 - 10,4
m = '05 — (0,015 m)
BARE HULL
PERIOD OF WAVE = '86 SEC
PERIOD OF MODEL = 3'13 "
HEIGHT OF WAVE = 5"0 — (12,7 cm)
LENGTH OF WAVE = 15'6 — (4,76 m)
LENGTH CONTRACTED.
(9,55 cm)
(7,62 cm)
(17,9 cm)
(9,02 cm)
(9,37 cm)
(18,2 cm)

Fig. 5.

the water-line, this center was above the center of gravity, and when the center of gravity was above the water-line, this quiescent center was below the center of gravity. It did not appear, however, that this center remained in quite the same position throughout the roll.

We know, in theory, that for unresisted rolling in still water, the period is given by the following formula:

$$P = \frac{2\pi\rho}{\sqrt{gm}}$$

where P is the complete or cyclic period of roll in seconds, ρ is the radius of gyration of the vessel about its center of gravity, m is metacentric height and g is acceleration due to gravity.

For ordinary ships, although we frequently know the metacentric height, the radius of gyration is not known, so the formula is not of much practical value; but it is more or less used, in practice, to arrive at the radius of gyration from observations of the rolling period in still water. But since actual rolling is resisted, there is some question as to the accuracy of the values of ρ so determined.

A number of the models tried at the Experimental Model Basin were carefully weighted and inclined in order to determine their metacentric height, and also swung in a hanging cradle in order to enable their radii of gyration, as weighted, to be determined. The dimensions of three of these models are as follows:

Model No.	Length Feet.	Breadth at LWL. Feet.	Draft. Feet.	Displacement. Pounds.	Transverse Metacenter. Feet.
1650	20.0	2.926	1.139	2500	at L.W.L.
1651	20.0	3.193	1.044	2500	0.2 ft. above LWL.
1652	20.0	3.436	0.970	2500	0.4 ft. above LWL.

In Metric Units.

Model No.	Length Meters.	Breadth at LWL. Meters.	Draft. Meters.	Displacement. Kg.	Transverse Metacenter. Meters.
1650	6.095	0.892	0.347	1134	at L.W.L.
1651	6.095	0.973	0.318	1134	0.061 above LWL.
1652	6.095	1.047	0.296	1134	0.122 above LWL.

Each model was tried with exceptionally large keels, 1.8 (.046 m.) inches, or some 15 per cent of the draft, in depth and

10 ft. (3.05 m.) long on each side; also, with the middle third of the keels removed, and with all of the bilge-keels removed. Four metacentric heights were used, ranging from a very small metacentric height of 0.044, of the draft of the vessel, to a very large one of about 0.36 of the draft. In the following table will be found the theoretical period of unresisted swing of each model, in each condition, calculated from the formula, $\frac{P}{2}=\frac{\pi\rho}{\sqrt{gm}}$, and the actual swing period as observed in careful rolling trials in still water.

Time in Seconds for 1 Swing or ½ Period.

Model No.	Bilge Keels	1650 Observed	1650 Calculated	1651 Observed	1651 Calculated	1652 Observed	1652 Calculated
GM 0.35 ft. / 0.107 m.	full	.94		1.12		1.17	
	⅓ off	.95	.954	1.10	1.040	1.15	1.100
	none	.94		1.05		1.12	
GM 0.25 ft. / 0.076 m.	full	1.21		1.36		1.41	
	⅓ off	1.18	1.130	1.34	1.274	1.41	1.338
	none	1.16		1.29		1.34	
GM 0.15 ft. / 0.046 m.	full	1.63		1.78		1.87	
	⅓ off	1.61	1.505	1.75	1.678	1.86	1.763
	none	1.53		1.67		1.79	
GM 0.05 ft. / 0.015 m.	full	2.94		3.27		3.36	
	⅓ off	2.89	2.740	3.20	2.996	3.33	3.083
	none	2.83		2.96		3.13	

It will be seen that the actual periods are remarkably close to the theoretical periods, and that the effect of the excessively large bilge keels upon the period is not great. It would seem, then, that we could rely upon the radii of gyration of actual ships, as determined by rolling experiments, with a good deal of confidence.

Incidentally, it is interesting to note that the declining-angle curves varied remarkably little with metacentric height. Thus, Fig. 6 shows eight declining-angle curves for model No. 1652, four being with bare hull and metacentric heights ranging from 0.05 of a foot to 0.35 of a foot (0.015 m. to 0.107 m.), and the other four being with full bilge-keels and the same metacentric heights. It should be remembered that these declining-angle curves are plotted upon roll numbers and not upon time. The vessel of large metacentric height, rolling more quickly than the vessel of small metacentric height, would have a given roll extinguished in less time, but it would take about the same number of rolls as for the vessel of small metacentric height.

APPENDIX I.

FORMULAE FOR SHIPS' LINES.

Water-Lines and Sectional-Area Curves.

In dealing with curves of this nature by means of mathematical formulae, it is obviously advantageous to treat separately the portions forward and aft of the greatest ordinate.

If we consider certain characteristics of water-line and sectional-area curves we find:

(a) At the greatest ordinate, the curve must be parallel to the center line.

(b) The curve must pass through the extremity of the greatest ordinate.

(c) The coefficient of fullness will vary and must be controlled.

(d) The angle at which the curve meets the center line at the end will vary and must be controlled.

(e) The curvature amidships or at the bow will vary and must be controlled.

To meet these five conditions, a mathematical formula must have five corresponding parameters. A parabola of the fifth degree naturally suggests itself, the origin for the curve being at the bow or stern. To fix our ideas, we will consider only forward lines in deriving the formulae, but after lines follow identical methods.

Take for the general equation

$$y = tx + ax^2 + bx^3 + cx^4 + dx^5 \tag{1}$$

Then

$$\frac{dy}{dx} = t + 2ax + 3bx^2 + 4cx^3 + 5dx^4 \tag{2}$$

$$\frac{d^2y}{dx^2} = 2a + 6bx + 12cx^2 + 20dx^3 \tag{3}$$

t is the tangent at the bow or origin and we have remaining four arbitrary parameters, a, b, c and d. Hence we can make the above equations fulfill four additional conditions. We assume for the mathematical work that ½ length and ½ beam are both unity. The resulting unit curve, as it is called, is readily expanded to the actual dimensions.

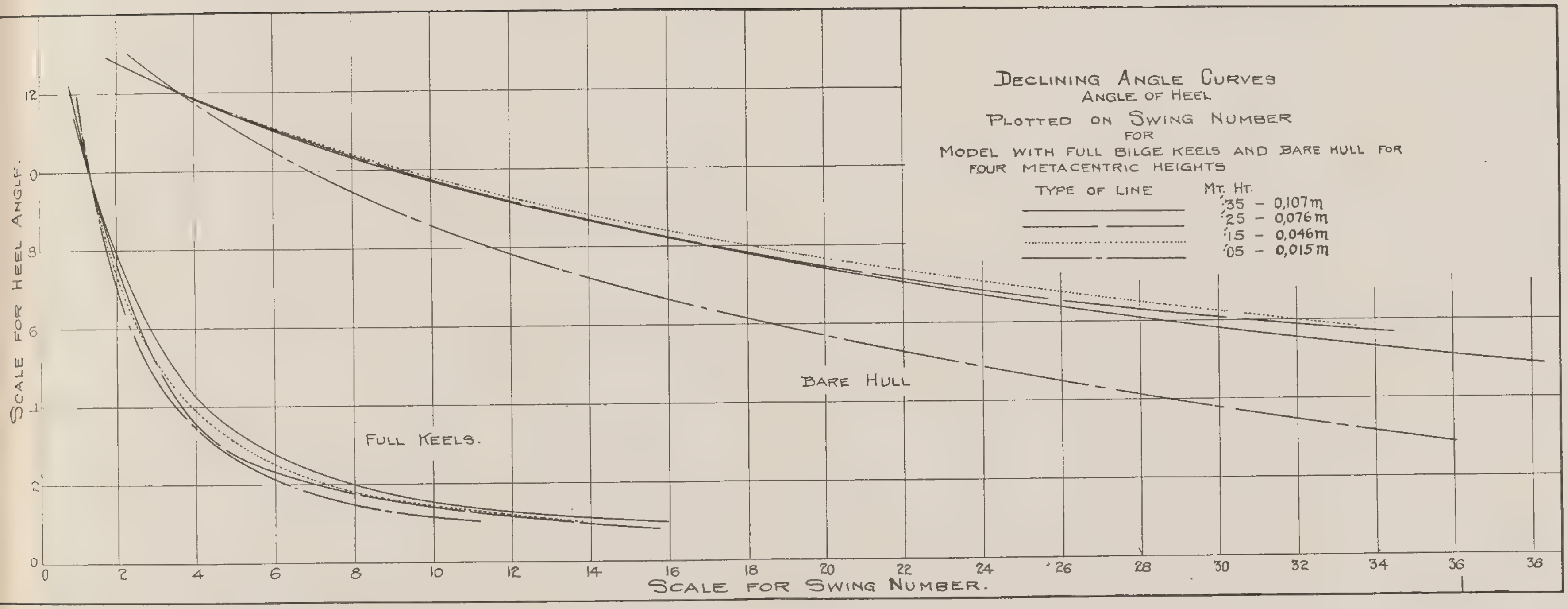

Declining Angle Curves
Angle of Heel
Plotted on Swing Number
for
Model with full bilge keels and bare hull for
four metacentric heights
Type of line
Mt. Ht.
·35 – 0,107m
·25 – 0,076m
·15 – 0,046m
·05 – 0,015m
Bare Hull
Full Keels.
Scale for Heel Angle.
Scale for Swing Number.
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38

Fig. 6.

Imposing the conditions that the curve shall pass through the point $x = 1$, $y = 1$; that its coefficient of fullness shall be p; that when $x = 1$ the tangent to the curve shall be zero; and that when $x = 1$ the acceleration $\frac{d^2y}{dx^2}$ shall be α, we obtain the following four equations:

$$\alpha_1 = 2a + 6b + 12c + 20d \qquad (4)$$

$$p - \frac{t}{2} = \frac{a}{3} + \frac{b}{4} + \frac{c}{5} + \frac{d}{6} \qquad (5)$$

$$1 - t = a + b + c + d \qquad (6)$$

$$-t = 2a + 3b + 4c + 5d \qquad (7)$$

Upon solving the above for a, b, c and d, we obtain:

$$a = 60p - 6t - 30 - \tfrac{1}{2}\alpha_1 \qquad (8)$$

$$b = -180p + 12t + 100 + 2\alpha_1 \qquad (9)$$

$$c = 180p - 10t - 105 - 2.5\alpha_1 \qquad (10)$$

$$d = -60p + 3t + 36 + \alpha_1 \qquad (11)$$

Substituting these values in the original equation (1) and arranging as below, we have:

$$\begin{aligned} y = &-30x^2 + 100x^3 + 105x^4 + 36x^5 \qquad (12)\\ &+ p\,(60x^2 - 180x^3 + 180x^4 + 60x^5)\\ &+ t\,(x - 6x^2 + 12x^3 - 10x^4 + 3x^5)\\ &+ \frac{\alpha_1}{2}\,(-x^2 + 4x^3 - 5x^4 + 2x^5) \end{aligned}$$

This may be written

$$y = C_y + p\,C_p + t\,C_t + \alpha_1\,C_{\alpha_1} \qquad (13)$$

where C_y, C_p, C_t and C_{α_1} are functions of x only, and independent of the parameters p, t and α_1.

Tables I and II show the values of C_y, etc., for sufficient values of x to enable all needed points on a curve to be calculated.

In a given case p is fixed and we shall need to select suitable values of t and α_1. Since the curve will never be concave at the center, α_1 will never have a positive value; it will be zero or negative. It will evidently be an aid, in this connection, to know the acceleration at the origin, α_o, that will result from given values of t, α_1, and p.

Differentiating the general equation (12) twice with respect to x, we have, when $x = 0$:

$$\alpha_0 + \alpha_1 = 120p - 60 - 12t. \qquad (14)$$

Now, we need some method or diagram which will enable us, for a given p, to know the range of t and a_1 for practicable curves, and also the effect upon our curves of variations of t and a_1.

There are two broad types of curves possible, namely, those with and those without a point of inflection. Where there is a

CALCULATION OF WATER LINE BY ACCELERATION FORMULA

NAME OF SHIP .... $y = tx + ax^2 + bx^3 + cx^4 + dx^5$ MODEL NO. ....

SOLVED:- $y = C_y + pC_p + tC_t + \alpha_1 C_\alpha$

where C_y is a constant; p = coefficient of fineness; t = unit tangent at x_0; α_1 = acceleration at $x = 1$.

α_1 may be zero or negative. $B = \frac{1}{2}$ MAX. L.W.L. BREADTH.

α_0 is negative for full lines. $L = \frac{1}{2}$ LENGTH.

α_0 is positive for hollow lines.

Bow. p = ·64 $t = \frac{L}{B}\frac{dy'}{dx'}$ = 1·10 $\alpha_1 = \frac{L^2}{B}\frac{d^2y'}{dx'^2}$ = 0 B = 23·750

STATION	F.P.	1	2	4	6	8	10	12	14	16	18	20
C_t	0	·03644	·05103	·04096	·01029	¯·01728	¯·03125	¯·03072	¯·02079	¯·00896	¯·00153	0
C_α	0	¯·00102	¯·00324	¯·00768	¯·00882	¯·00576	0	·00576	·00882	·00768	·00324	0
C_p	0	·12858	·4374	1·2288	1·8522	2·0736	1·8750	1·3824	·7938	·3072	·0486	0
C_y	0	−·0631	−·2101	−·5565	−·7630	−·7194	−·4375	−·0086	·4400	·7885	·9671	1·0000
tC_t	0	·0823	·2799	·7865	1·1853	1·3270	1·2000	·8848	·5080	·1966	·0311	0
$\alpha_1 C_\alpha$	0	0	0	0	0	0	0	0	0	0	0	0
pC_p	0	·0401	·0561	·0451	·0113	¯·0190	¯·0344	¯·0338	¯·0229	¯·0099	¯·0017	0
$+\Sigma$	0	·1224	·3360	·8316	1·1966	1·3270	1·2000	·8848	·9480	·9851	·9982	1·0000
$-\Sigma$	0	·0631	·2101	·5565	·7630	·7384	·4719	·0424	·0229	·0099	·0017	0
y	0	·0593	·1259	·2751	·4336	·5886	·7281	·8424	·9251	·9752	·9965	1·0000
By	0	1·408	2·990	6·534	10·298	13·979	17·292	20·007	21·971	23·161	23·667	23·750

STERN p = ·75 $t = \frac{L}{B}\frac{dy'}{dx'}$ = ·250 $\alpha_1 = \frac{L^2}{B}\frac{d^2y'}{dx'^2}$ = 0 B = 23·750

STATION	A.P.	39	38	36	34	32	30	28	26	24	22	20
C_y	0	¯·0631	¯·2101	¯·5565	¯·7630	¯·7194	¯·4375	¯·0086	·4400	·7886	·9671	1·0000
tC_t	0	·0911	·1276	·1024	·0257	¯·0432	¯·0781	¯·0768	¯·0520	¯·0224	¯·0038	0
$\alpha_1 C_\alpha$	0	0	0	0	0	0	0	0	0	0	0	0
pC_p	0	·0964	·3281	·9216	1·3892	1·5552	1·4063	1·0368	·5954	·2304	·0365	0
$+\Sigma$	0	·1875	·4557	1·0240	1·4149	1·5552	1·4063	1·0368	1·0354	1·0189	1·0036	1·0000
$-\Sigma$	0	·0631	·2101	·5565	·7630	·7626	·5156	·0854	·0520	·0224	·0038	0
y	0	·1244	·2456	·4675	·6519	·7926	·8907	·9514	·9834	·9965	·9998	1·0000
By	0	2·955	5·833	11·103	15·483	18·824	21·154	22·596	23·356	23·667	23·745	23·750

Table I.

point of inflection, it is desirable to know how its position varies with t and a_1. By equating the second differential of the general equation to zero, we shall obtain an equation giving the relations

CALCULATION OF SECTIONAL-AREA CURVE BY ACCELERATION FORMULA.

NAME OF SHIP.................. $y = tx + ax^2 + bx^3 + cx^4 + dx^5$. MODEL NO. ....

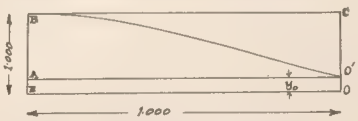
SOLVED:- $y = C_y + l\,C_l + t\,C_t + \alpha_1 C_\alpha$.

where C_y is a constant; l = longitudinal coef. t = unit tangent at x_0; α_1 = acceleration at $x = 1$.

α_1 may be zero or negative
α_0 is negative for full lines
α_0 is positive for hollow lines

$M = \frac{1}{2}$ Sectional Area.
$L = \frac{1}{2}$ Length.

C.G. OF MATHEMATICAL CURVE FROM END = $\frac{1}{l}(\cdot 1429 + \cdot 4286\,l - \cdot 0048\,t + \cdot 0012\,\alpha_1)$



l = LONGITUDINAL COEF. EBO′OE
l_m = " " ABO′A = $\dfrac{l - y_0}{1 - y_0}$

Bow. l = ·5826 l_m = ·5719 $t = \frac{L}{M}\frac{dy'}{dx'}$ = ·80 $\alpha_1 = \frac{L^2}{M}\frac{d^2y'}{dx'^2}$ = −·25 M = 360·525

STATION	F.P.	1	2	4	6	8	10	12	14	16	18	20
C_t	0	·03644	·05103	·04096	·01029	−·01728	−·03125	−·03072	−·02079	−·00896	−·00153	0
C_α	0	−·00102	−·00324	−·00768	−·00882	−·00576	0	·00576	·00882	·00768	·00324	0
C_l	0	·12858	·4374	1·2288	1·8522	2·0736	1·8750	1·3824	·7938	·3072	·0486	0
C_y	0	−·0631	−·2101	−·5565	−·7630	−·7194	−·4375	−·0086	·4400	·7885	·9671	1·0000
$t\,C_t$	0	·0292	·0408	·0328	·0082	−·0138	−·0250	−·0246	·0166	−·0072	−·0012	0
$\alpha_1 C_\alpha$	0	·0026	·0081	·0192	·0221	·0144	0	−·0144	−·0221	−·0192	−·0081	0
$l\,C_l$	0	·0735	·2501	·7026	1·0592	1·1858	1·0723	·7905	·4540	·1757	·0278	0
$+\Sigma$	0	·1053	·2990	·7546	1·0895	1·2002	1·0723	·7905	·8940	·9642	·9949	1·0000
$-\Sigma$	0	·0631	·2101	·5565	·7630	·7332	·4625	·0476	·0387	·0264	·0093	0
Σ	0	·0422	·0889	·1981	·3265	·4670	·6098	·7429	·8553	·9378	·9856	1·0000
$(1-y_0)\Sigma$	0	·0411	·0867	·1931	·3183	·4553	·5945	·7242	·8338	·9142	·9608	·9750
y	·0250	·0661	·1117	·2181	·3433	·4803	·6195	·7492	·8588	·9392	·9858	1·0000
My	9·0	23·831	40·271	78·631	123·768	173·160	223·345	270·105	309·619	338·605	355·406	360·525

STERN. l = ·5826 $t = \frac{L}{M}\frac{dy'}{dx'}$ = ·5 $\alpha_1 = \frac{L^2}{M}\frac{d^2y'}{dx'^2}$ = 0 M = 360·525

STATION	A.P.	39	38	36	34	32	30	28	26	24	22	20
C_y	0	−·0631	−·2101	−·5565	−·7630	−·7194	−·4375	−·0086	·4400	·7885	·9671	1·0000
$t\,C_t$	0	·0182	·0255	·0204	·0051	−·0086	−·0156	−·0153	−·0104	−·0045	−·0007	0
$\alpha_1 C_\alpha$	0	0	0	0	0	0	0	0	0	0	0	0
$l\,C_l$	0	·0749	·2548	·7160	1·0790	1·2080	1·0923	·8055	·4625	·1790	·0286	0
$+\Sigma$	0	·0931	·2803	·7364	1·0841	1·2080	1·0923	·8055	·9025	·9675	·9954	1·0000
$-\Sigma$	0	·0631	·2101	·5565	·7630	·7280	·4531	·0239	·0104	·0045	·0007	0
y	0	·0300	·0702	·1799	·3211	·4800	·6392	·7816	·8921	·9630	·9947	1·0000
My	0	10·816	25·309	64·858	115·765	173·052	230·448	281·786	321·624	347·186	358·614	360·525

Table II.

between x, which will now be the abscissa of the point of inflection, and p, t and a_1. This equation, linear as regards p, t and a_1, but of the third degree in x, is as follows:

$$\begin{aligned} a = 0 = & -60 + 600x - 1260x^2 + 720x^3 \\ & + p\,(120 - 1080x + 2160x^2 - 1200x^3) \\ & + t\,(-12 + 72x - 120x^2 + 60x^3) \\ & - a_1\,(1 - 12x + 30x^2 - 20x^3) \end{aligned} \tag{15}$$

Suppose now, for a given value of a_1, we imagine a series of lines drawn with p and t as abscissae and ordinates respectively, each line corresponding to one value of x. Draw the envelope or the curve touching all the lines and locate along it a scale showing the values of x. This envelope, or locus, for the given value of a_1, is evidently such that if from any point fixed by its values of p and t we draw a tangent to the locus, the water-line or sectional-area curve determined from the formula, having the values of p and t of the chosen point and of a_1 for the locus, will have a point of inflection at the value of x determined by the point of tangency on the locus for a_1.

In order to trace the loci, use x as a parameter and express p and t in terms of x and a_1 only.

Eliminating successively t and p from the general equation (15) and its differential and reducing, we have

$$p = \frac{15x^2 - 14x + 4}{20x^2 - 20x + 6} + a_1 \frac{50x^4 - 120x^3 + 105x^2 - 40x + 6}{60\,(1 - x)^2\,(20x^2 - 20x + 6)} \tag{16}$$

$$t = \frac{60x^2 - 40x + 10}{20x^2 - 20x + 6} + a_1 \frac{20x^4 - 40x^3 + 28x^2 - 8x + 1}{2\,(1 - x)^2\,(20x^2 - 20x + 6)} \tag{17}$$

These equations give the loci required.

We may also eliminate a_1 from the above, giving,

$$\begin{aligned} 30\,p\,(20x^4 - 40x^3 + 28x^2 - 8x + 1) = \; & t\,(50x^4 - 120x^3 + 105x^2 - 40x + 6) \\ & + 10\,(30x^4 - 56x^3 + 36x^2 - 9x + 1) \end{aligned} \tag{18}$$

This last equation represents a straight line in p and t for a given value of x; and all values of a_1, for a given value of x, are found upon this straight line, which we may call, for convenience, an x line.

It appears obvious that for water-lines and curves of sectional area we would not think of having a point of inflection for a greater value of x than 0.5. So let us investigate the case of $x = 0.5$.

Putting $x = 0.5$ in the general x-line equation (18), we obtain

$$t = 20p - 10 \tag{19}$$

Also for the a_1 contours, equations (16) and (17). When $x = \frac{1}{2}$ we have $\frac{dt}{dp} = 20$. Hence where the a_1 contours meet the line in p and t, for $x = 0.5$, they have the same inclination as the x line, that is, they are tangent to it.

Then the line for $x = 0.5$ is evidently an important line, since for points on one side of it there will, for a given value of a_1, be a point of inflection below $x = 0.5$, and for points on the other side, a point of inflection beyond $x = 0.5$.

The loci represented by equations (16) and (17) are shown plotted in Fig. 7, together with a number of x lines and other data needed.

The complete loci are not shown, but only the portion extending from $x = 0$ to $t = 0$, except the locus for $a_1 = 0$ which is shown from $x = 0$ to $x = 1$. Parts of the loci not shown in the figure are of no value for our purposes.

To illustrate the use of these curves, let us select one, say for $a_1, = -1$, shown separately in Fig. 8.

Now, if we remember that this curve is the envelope of a series of straight lines in p and t with a fixed value of $a_1 = -1$, and that the points of tangency with these straight lines give the values of x, or fraction of water-line length at which points of inflection occur in the derived water-line or sectional-area curves, it will aid in fixing clearly in our minds their meaning.

Starting at A on axis of p, the contour extends as $ABCDE$ to the point E, corresponding to $x = 0$. There are indicated around the contour the various values of x. At E, where $x = 0$, is drawn the tangent EF, which cuts the curve at B and the axis of p at H. The point marked D corresponds to $x = 0.5$, and the tangent DG is drawn.

Now, if we choose p and t so as to locate a spot within the area $EBCDE$, we evidently cannot draw a tangent to the contour, and, hence, the curve of sectional areas or water-line corresponding to the spot will have no point of inflection for $a_1 = -1$.

Below the line HEF and to the left of AB, that is, in the area $HEBAH$, we can draw one tangent to the contour, with a

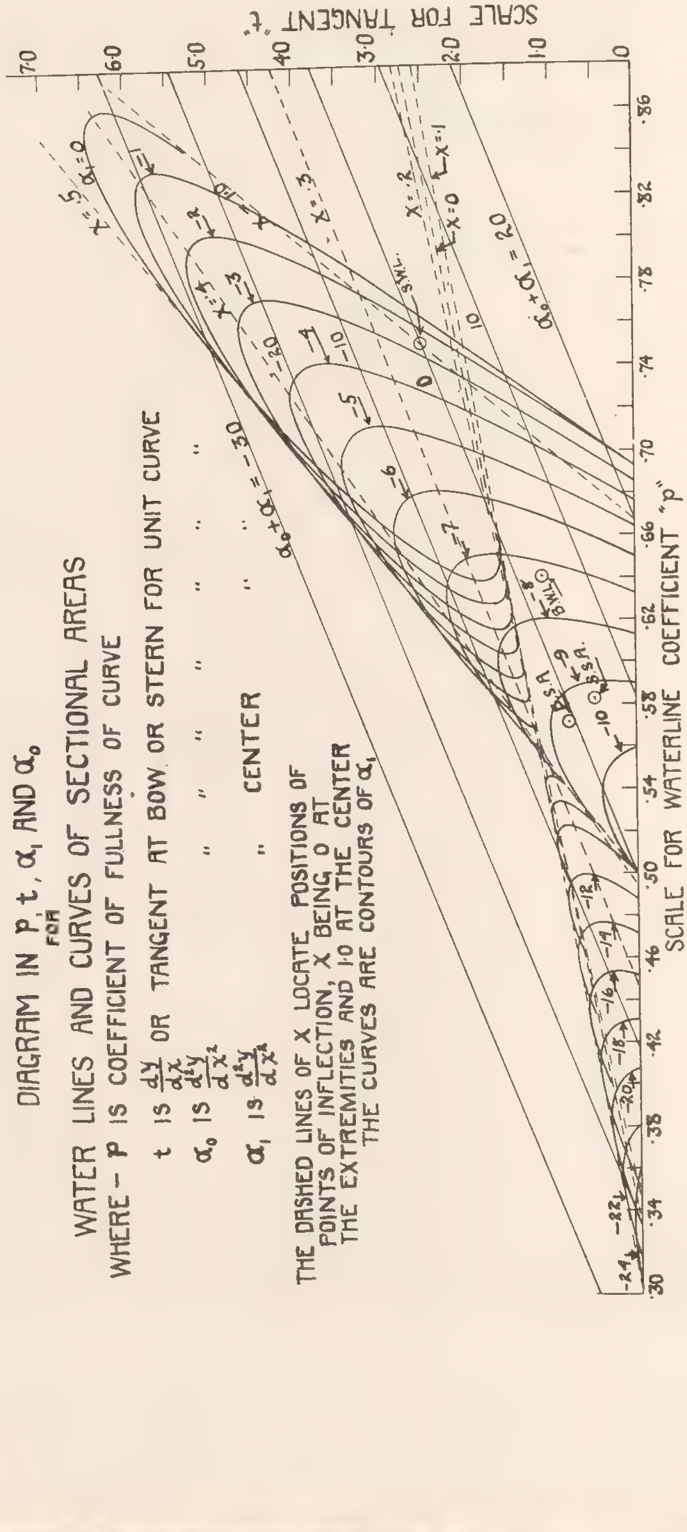


DIAGRAM IN P, t, α₁ AND α₀ FOR
WATER LINES AND CURVES OF SECTIONAL AREAS
WHERE – P IS COEFFICIENT OF FULLNESS OF CURVE
t IS dy/dx OR TANGENT AT BOW OR STERN FOR UNIT CURVE
α₀ IS d²y/dx² " " " " " "
α₁ IS d²y/dx² " CENTER " "
THE DASHED LINES OF X LOCATE POSITIONS OF POINTS OF INFLECTION, X BEING 0 AT THE EXTREMITIES AND 1·0 AT THE CENTER
THE CURVES ARE CONTOURS OF α₁
SCALE FOR TANGENT "t"
SCALE FOR WATERLINE COEFFICIENT "p"
α₀ + α₁ = −30
α₀ + α₁ = 20
S.W.L.
B.W.L.
S.S.A.
B.S.A.

Fig. 7.

point of tangency somewhere between E and D, and, hence, a point of inflection on the desired curve between $x = 0$ and $x = 0.5$.

This is a useful area, giving derived curves that are hollow or have a point of inflection towards the extremity.

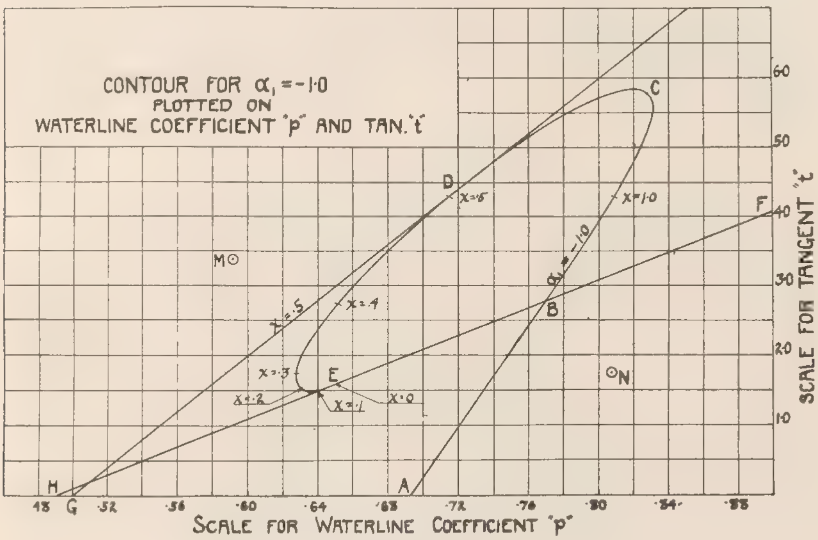


Fig. 8.

But if we choose p and t for a point such as M, which is above HEF and outside the contour, we shall have two tangents to the contour and two points of inflection of the derived curve, thus obtaining a type of curve not usually regarded as suitable for water-lines or curves of sectional area.

If we use a point such as N, which is below HEF and to the right of AB, we shall be able to draw three tangents to the contour. One of these will touch below the axis of p, on a part of the locus not shown. Such a derived curve will be of no practical use.

We conclude, then, that the useful part of the diagram, or the area for useful values of p and t, is the area $HEDCBAH$.

For points in this area above HEF we shall have no point of inflection in derived curves, and, hence, they will be convex throughout their length.

For points below *HEF* we shall have a point of inflection toward the end, and the derived curves will be hollow or concave at the ends and convex or rounding towards amidships.

Consider, now, Fig. 9, which shows the contour for $a_1 = -7$. Here the area for which there is no point of inflection has been reduced to the small area above *HEF* and below the curve. There is a cusp at *K* for which $x = 0.338$.

For the small area above the cusp and below *HEF* it is possible to draw three tangents to the contour, so this is an undesirable area.

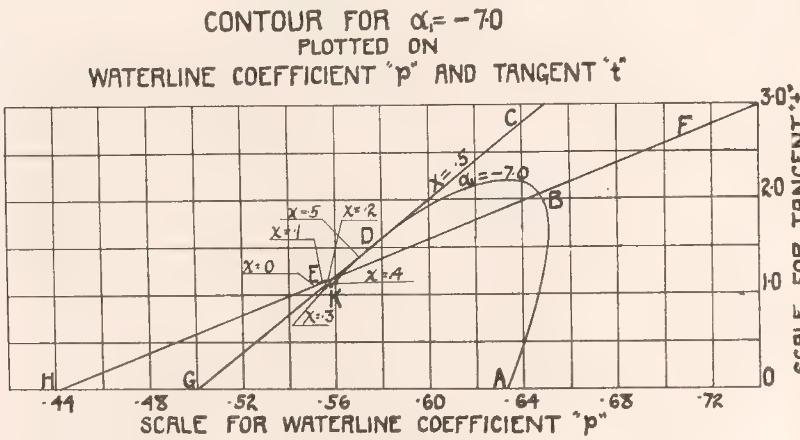


Fig. 9.

For all other points outside the area *ABDKEHA* it is possible to draw two tangents to the contour. So this area is not profitable.

For two points inside the area *ABDKEHA* but one tangent can be drawn to the contour, but if the point is to the left of *DG* ($x = 0.5$), the tangent is for a greater value of x than 0.5, so that the point of inflection is more than half-way from the end to the center. This is not likely to be desired.

As the values of a_1 become numerically greater, the cusp rapidly becomes more pronounced. When $a_1 = -10$, the conditions are as in Fig. 10.

All of the contour is now below *HEF* and there is no derived curve possible without at least one point of inflection. The

cusp is at G, upon the base line, or $t = 0$, and the line $x = 0.5$ is tangent at the cusp.

The area for which only one point of inflection will be found in the derived curve is $ACGLEHGA$, and for the area $GLEHG$ the point of inflection will be beyond $x = 0.5$. As a_1 increases numerically beyond -10, the cusp point passes below $t = 0$ and we have two distinct branches of the a_1 contour. This does not last long, however, since the right-hand branch, corresponding to ACG in Fig. 10, is entirely below the line when a_1 passes the value — 10.65.

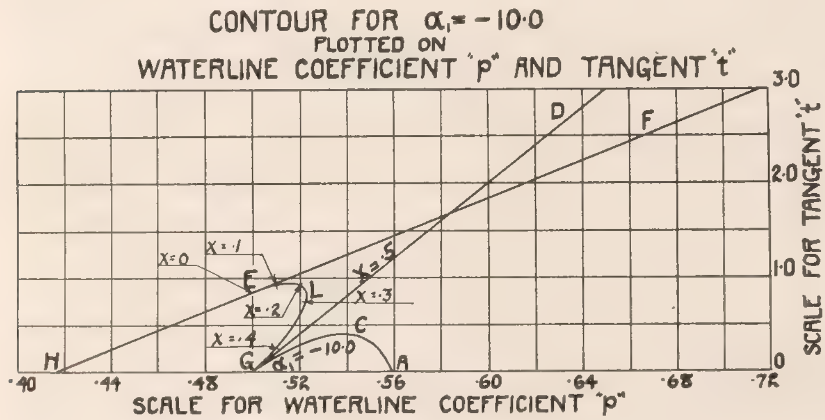


Fig. 10.

The left branch, corresponding to GLE in Fig. 10, has a portion above the $t = 0$ line until $a_1 = -25.35$, when it, too, disappears below, where $p = 0.3146$.

This, then, is the extreme value of a_1 that can be used in the formula and still have a curve with but a single point of inflection. It also corresponds very nearly to the minimum value of p. The absolute minimum value of p possible with but one point of inflection is $p = 0.3064$.

In practice, however, we are not concerned with these small values of p and extreme values of a_1.

Water-lines and curves of sectional area have coefficients below 0.5 only for abnormal cases, and it is seldom, indeed, that we need, in practical cases, consider values of a_1 outside the range from 0 to — 6. So the contours with cusps, etc., in Fig. 7

are of no practical importance. It will be noted that Fig. 7 shows lines of $a_0 + a_1$. These enable us, when we have chosen a spot from values of p and t and settled on a_1, to ascertain at once a_0, or the nature of curvature at the bow.

In certain classes of vessels, it may be desirable to locate the fore and aft position of the center of buoyancy to accommodate the center of gravity of weights, rather than shift weights to

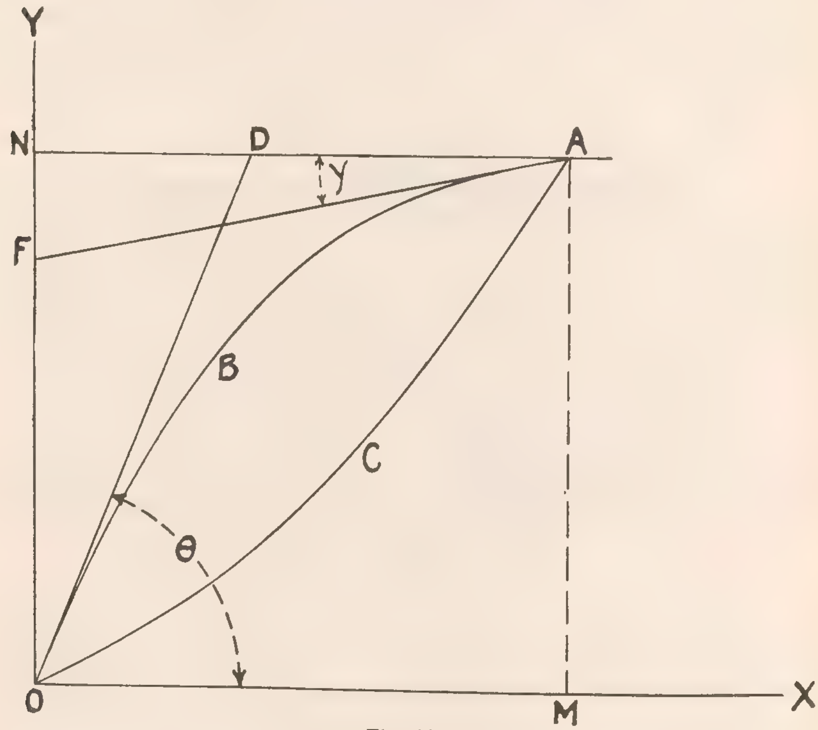


Fig. 11.

accommodate the center of buoyancy, and also to determine the center of gravity of water planes. This is readily done as soon as the constants p, t and a_1 are chosen for the water-line.

By integrating the general equation (1) for area and moments, and substituting values of a, b, c and d as given in equations (8), (9), (10) and (11), we obtain the distance, x_b, of the center of gravity from the origin:

$$x_b = \frac{1}{p}(.1429 + .4286p - .0048t + .0012a_1) \qquad (20)$$

The position of the center of gravity having been found for each end separately, the position for the whole curve is readily determined. It will be seen in Table II that the same formula may be used to determine the center of buoyancy when we know for the sectional-area curve t, a_1 and l, the longitudinal coefficient.

Curves for Sections.

Referring to Fig. 11, there are indicated from O to A two curves suitable for sections, OBA being a full curve of sectional coefficient greater than 0.5 and OCA a fine curve of section coefficient less than 0.5. In each case, O, the origin, is placed at the keel, abscissae x representing distances up from the keel and ordinates y representing distances out from the center line. In other words, the half sections of Fig. 11 are on their sides. This is simply because it is customary in analytical geometry to represent vertical ordinates by y and horizontal abscissae by x, and in dealing with ship sections mathematically it is convenient to adhere to this custom.

Fig. 11 represents a unit section, MO, the draught, and MA, the half-breadth, at the water-line being each unity.

Consider now OD tangent at O to OBA. Evidently ND is the dimension in the unit section corresponding to the dead-rise and however we may change the draught and beam we shall always have

$$\frac{\text{Dead-rise}}{\text{Draught}}=\frac{ND}{NA};$$

or, since in the unit section NA is equal to 1, we shall have

$$\frac{\text{Dead-rise}}{\text{Draught}}=ND=\text{Dead-rise fraction.}$$

We shall, however, find it convenient in formulae to work not with ND, the dead-rise fraction, but with the tangent of the angle DOX, denoted by Θ.

For the unit section, Θ, or DOX, is the same as ODN, and $\tan.\ \Theta=\tan.\ ODN=\frac{ON}{DN}=\frac{1}{ND}$ for unit section where $ON=1$.

Denote tan. Θ by l, which, being the reciprocal of the dead-rise fraction, is therefore a parameter of the dead-rise.

The relation between the dead-rise as ordinarily used for

actual sections and the quantity l, which is the dead-rise parameter for the unit section, is given by:

$$\text{Tan. } (90° - \delta) = l\frac{B}{2H} \tag{1}$$

$$l = \frac{\text{Actual Draught}}{\text{Actual Dead-rise}} = \frac{H}{d} \tag{2}$$

Where δ is the dead-rise angle, B the whole beam, and H the draught of the full-sized section.

The relation between the flare, f, of the unit section and the flare angle, γ, of the full-sized section is:

$$\text{Tangent } \gamma = f\frac{B}{2H}$$

The angle NAF in the unit section of Fig. 11 is the flare angle. For this unit section $f = \tan.\ \gamma$.

While a great many formulae have been tried for section curves, it has not been found possible to devise one which is satisfactory for all sectional coefficients. Hence, under present methods, we make use of two formulae, one for sections of fine coefficient and one for sections of full coefficient, shifting from one to the other at some convenient section of intermediate coefficient where the two formulae give substantially identical results.

Fourth-Degree Parabola for Sections.

For fine sections, the basic unit-section formula used is the parabola of the fourth degree

$$y = lx + ax^2 + bx^3 + cx^4 \tag{4}$$

The line represented by this formula passes through the origin, where $x = 0$ $y = 0$, and has the proper tangent l at the origin.

There are three arbitrary constants, a, b, and c, so we may impose three conditions. These are: First, that the curve shall pass through the point where the section meets the water-line, which for the unit section is the point $x = 1$ $y = 1$. Second, that at the water-line the tangent of the inclination of the curve to the axis of x shall be f, the flare. Third, that the area of this section, or curve, from $x = 0$ to $x = 1$, shall be the required sectional area, or, for the unit curve, the coefficient of fineness, m.

Imposing these conditions on equation (4), we obtain equations from which a, b and c are determined in terms of l, f and m,

the known optional quantities. The general methods are the same as when dealing with the fifth-power formula for water-lines, etc. Using these values in the original equations, we obtain:

$$y = Y + Mm + Ff + Ll \tag{5}$$

Where Y, M, F and L are functions of x only; hence, we may calculate, once for all, sufficient values of Y, M, F and L to enable

CALCULATIONS FOR SECTIONS BY HYPERBOLIC FORMULA

MODEL No.............. REPRESENTING....................

FORMULA $y = fx + (1-f)\phi(x)$

STATION No. 12 — B_2 19257 . m 8.2 . . f .032 . . $1-f$ .968 . . m_0 92 6

x	005	0	02	03	05	07		15	2	3	4	5	6	7	8	9	12
$\phi(x)$			[illegible]		[illegible]	3535	4535	[illegible]	6745	[illegible]	8775	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
$(1-f)\phi(x)$			200		[illegible]	[illegible]	[illegible]	[illegible]	6529	[illegible]	8494	[illegible]	[illegible]	[illegible]	[illegible]	9655	
fx			0016		[illegible]	0022	0032	0048	0064	0096	0128	0160	[illegible]	0224	0256	0288	
y			206		2656	3444	4422	[illegible]	6593	7840	8622	9134	[illegible]	[illegible]	[illegible]	[illegible]	
B_2y			232		[illegible]	663	852	1093	[illegible]	1510	1660	1759	1824	[illegible]	[illegible]	[illegible]	

STATION No. 20 — B_2 23.00 . . m . 9.73 . . f . . 0 . . $1-f$ . . . . m_0 . . .

x	005	0	02	03	05	07	1	15	2	3	4	5	6	7	8	9	[illegible]
$\phi(x)$			3450		5828	6720	7568	8395	8870	9390	9650	9805	[illegible]	9950	9975	9990	
$(1-f)\phi(x)$																	
fx																	
y																	
B_2y			793		[illegible]	545	1741	1931	2040	[illegible]	2220	2255	2274	2288	2294	2298	

CALCULATIONS FOR SECTIONS BY FOURTH POWER FORMULA.

MODEL No.............. REPRESENTING..........

— FORMULA —

$y = Y + Mm + Ff + Ll$

STATION No. 30 — B_2 = . 18024 m = . 5388 . . f = . 333 l = . 75 . .

x	0	03	05	07	1	15	2	3	4	5	6	7	8	9	12
M	[illegible]	0254	06769	.2714	2430	4877	7680	373	17280	18750	7280	[illegible]	[illegible]	2430	728
F	00015	00024	00327	00604	[illegible]	02152	0320	[illegible]	04800	03125	0	[illegible]	[illegible]	[illegible]	4320
L	[illegible]	02611	03948	04995	06075	06773	0640	03075	0	03125	-0480	-04725	[illegible]	[illegible]	0960
Y	[illegible]	0.0	0266	0496	0935	831	2800	4455	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mm			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Ff			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Ll			0296	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
$+\Sigma$			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
$-\Sigma$			0266	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4609	[illegible]	[illegible]	[illegible]	[illegible]	
y			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4350	5595	[illegible]	[illegible]	[illegible]	[illegible]	
B_2y			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Table III.

us to establish points upon any section at a sufficient number of values of x, as soon as values of m, f and l are known.

Table III of the "Calculations for Sections by Fourth-Power Formula" shows values of Y, M, F and L from $x = 0$ to $x = 1.2$, arranged in a form suitable for calculation.

It will be observed that since sections in practice have usually a certain width of flat keel, the form, Table IV, is arranged to provide for this, when necessary.

When working with models of not actual ships, and in theoretical work, generally, it is usually sufficient to regard the half-breadth of the keel as zero. In such cases, the portion of the form providing for the half-breadth of keel is simply not filled in.

By the use of the form shown in Table III we can determine the ordinates of a section corresponding to any values of m, f and

CONSTANTS FOR SECTIONS.

MATHEMATICAL LINES.

MODEL NO .... REPRESENTING ....

LENGTH, L 352'0" BREADTH, B 47'5" DRAFT, H 16'5" DISPLACEMENT, Δ 4700 TONS

$M = \frac{1}{2}$ MIDSHIP SECTIONAL AREA 360.525 SQ. FT. — $SA_1 = M \times$ FRACTION OF MAXIMUM SA — COEFFICIENTS

K = HALF BREADTH OF KEEL .75 — $SA_2 = SA_1 - HK$ — BLOCK .5360

HK = .2375 SQ. FT. — $m = \frac{SA_2}{B_2H}$ — WATER-LINE BOW .6400, STERN .7500, AVERAGE .6950

SA_1 = ACTUAL HALF SECTIONAL AREA — $m_o = \frac{m - \frac{f}{2}}{1-f}$

SA_2 = ACTUAL HALF SECTIONAL AREA CORRECTED FOR HK — MIDSHIP .9200

B_1 = HALF BREADTH OF SECTION AT L.W.L. — $f = \frac{2(m - m_o)}{1 - 2m_o}$ — LONGITUDINAL .5826

B_2 = HALF BREADTH OF SECTION AT L.W.L. CORRECTED FOR K — $l = \frac{1 - f(1-L)}{L}$ — $\frac{\Delta}{(\frac{L}{100})^3}$ 98.0 $\frac{B}{H}$ 2.88

f = FLARE l = DEAD RISE m = SECTIONAL COEFFICIENT

STATION	SA FRACT OF MAX	SA_1	SA_2	W.L. FRACT OF MAX	B_1	B_2	B_2H	m	MINIMUM f $4-6m$	MAXIMUM f $2-2m$	f	$\frac{f}{2}$	$m-\frac{f}{2}$	$1-f$	m_o	L	l	STATION
F.P.	.025	0		0	0	0	0											F.P.
1	066	[illegible]	450	.593	4.8	.658	10.857	.552										1
2	[illegible]	[illegible]	22.940	1259	[illegible]	[illegible]	30.960	[illegible]	-.5292	.4106	.350	.0250	.7297	.9500	.7652			2
4	[illegible]	[illegible]	66.256	.2751	[illegible]	.5734	45.436	.6442	-.1652	.616	.235	.1175	.5767	.7650	.7534			4
6	.3433	[illegible]	[illegible]	.4336	[illegible]	9.242	57.542	[illegible]	.2436	.5858	.300	.1500	.5571	.7000	.7959			6
8	.1503	[illegible]	60.785	.5886	[illegible]	3.229	[illegible]	.7366	-.496	.5268	.340	.1200	.6166	.7600	.8113			8
10	[illegible]	[illegible]	[illegible]	.7281	.7292	6.542	[illegible]	[illegible]	-.6574	.4542	.100	.0500	.7229	.9000	.8032			10
12	.7492	[illegible]	[illegible]	.8424	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.3776	[illegible]	.0160	.7952	.9680	.8210			12
14	.8588	[illegible]	[illegible]	.9251	[illegible]	[illegible]	350.147	.8439	-[illegible]	[illegible]	[illegible]	.0050	.8434	.9900	.8526			14
16	.9392	[illegible]	[illegible]	.9702	23.61	.224.1	364.30	.8835	.2932	[illegible]	.000							16
18	.9658	[illegible]	343.2[illegible]	.9955	.23661	[illegible]	378.13	.4072	-1.4432	.1836	.000							18
20	[illegible]	[illegible]	[illegible]	1.0000	[illegible]	23.000	[illegible]	[illegible]	-.5044	.1650	.300							20
22	.9947	[illegible]	[illegible]	.9993	[illegible]	22.945	379.43	.925	.4350	[illegible]	.200					.0433	.2310	22
24	.9630	[illegible]	334.8	.9965	[illegible]	[illegible]	378.131	.8854	.1324	[illegible]	.103	.0040	.88.4	.9920	.8886	.0640	.155.	24
26	.8921	[illegible]	309.244	.9834	.23356	.22606	372.998	[illegible]	-.9746	.34.6	.020	.0100	.3191	.9600	.9358	.1280	.780	26
28	.7916	[illegible]	.2694	.95.4	[illegible]	[illegible]	360.459	.7424	.4844	.5052	.355	.0275	.7.99	.9450	.7619	.2550	.375	28
30	.6392	[illegible]	[illegible]	.8907	[illegible]	.20.424	336.666	.6479	.132	.7044	.157	.0685	.5795	.5630	.6.73	.4865	.190	30
32	[illegible]	[illegible]	[illegible]	.7426	[illegible]	[illegible]	298.221	.5388	[illegible]	.9224	.333						.75	32
34	[illegible]	[illegible]	[illegible]	.65.9	.15.443	.4.733	247.95	.4253	1.4492	.1494	.720						.30	34
36	.799	[illegible]	32.483	.4675	[illegible]	.10.313	[illegible]	.3072	2.568	.3856	1.500						0	36
38	[illegible]	[illegible]	.2934	.2456	.5939	.5.383	[illegible]	.342										38
39	[illegible]	[illegible]		.244	.2955	.2.205	36.383											39
A.P.	0	0		0	0	0	0											A.P.

Table IV.

l. It is obvious, however, that we can not choose values of m, f and l at random, if we desire sections of ship-shaped form. Moreover, it is necessary that we shall know for a given value of m the possible variations of f and l for sections suitable for ship's use, so that the possibilities and limitations of the sections derivable from the formula must now be considered.

The sections commonly used for ships may be divided into three classes, namely, full sections, hollow sections, and S sec-

tions. Full and hollow sections show one kind of curvature from keel to water-line; while for the S section, there is a change of direction of curvature, or a point of inflection, at some place between the keel and the water-line.

To find the position of points of inflection, differentiate the original equation twice with respect to x, then put $\frac{d^2y}{dx^2}=0$ and substitute for a, b and c their values in l, m and f, and we have at a point of inflection

$$x^2(360m-30l+30f-180)-x(360m-36l+24f-168)+60m-9l+3f-24=0 \tag{6}$$

With a given value of f and a series of values of x we shall get a series of straight lines in l and m. If these straight lines have an envelope, it will be the contour of f for its given value. Along this contour, x will vary, its value at any point being determined by the point of tangency of the straight tangent line in l and m.

To see whether equation (6) has an envelope, differentiate it with respect to x and eliminate x between it and the differential. We shall thus obtain:

$$600(m-.5)^2-80(m-.5)(l-1)+80(m-.5)(f-1)+(l-1)^2-4(l-1)(f-1)+3(f-1)^2=0 \tag{7}$$

For a given value of f, this equation represents an ellipse in l and m.

To get the value of x at the point where a straight line in l and m is tangent to the ellipse, solving for x in equation (6) and introducing the condition expressed by equation (7), we shall have:

$$x=\frac{30m-3l+2f-14}{60m-5l+f-26} \tag{8}$$

Solving this equation and equation (6) we have:

$$l-1=-(f-1)\,\frac{60x^2-40x+10}{60x^2-80x+30} \tag{9}$$

$$m-.5=-(f-1)\,\frac{10x^2-10x+3}{60x^2-80x+30} \tag{10}$$

and

$$\frac{l-1}{m-.5}=\frac{60x^2-40x+10}{10x^2-10x+3} \tag{11}$$

These formulae, (9), (10) and (11), will enable us to plot the ellipse for any value of f, and locate on it the points for the

various values of x. It is seen that each radial line from $(l - 1) = 0$, $(m - 0.5) = 0$ cuts every ellipse at points having identical values of x. From the equations (9), (10) and (11) the curves in Fig. 12 are plotted.

Let us now examine one of the curves and interpret its physical meaning.

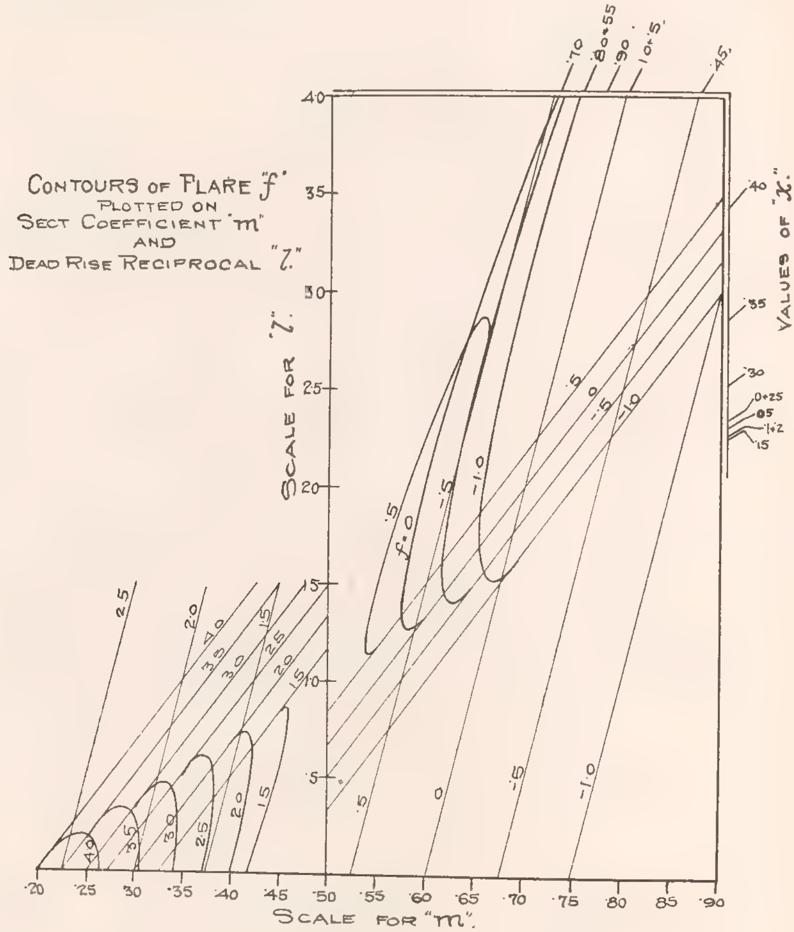


Fig. 12.

Fig. 13 shows the complete ellipses corresponding to $f = 0$ and $f = 1.25$, and there are located upon it a number of spots corresponding to various values of x by means of radial lines through $m = 0.5$, $l = 1$ corresponding to these values of x.

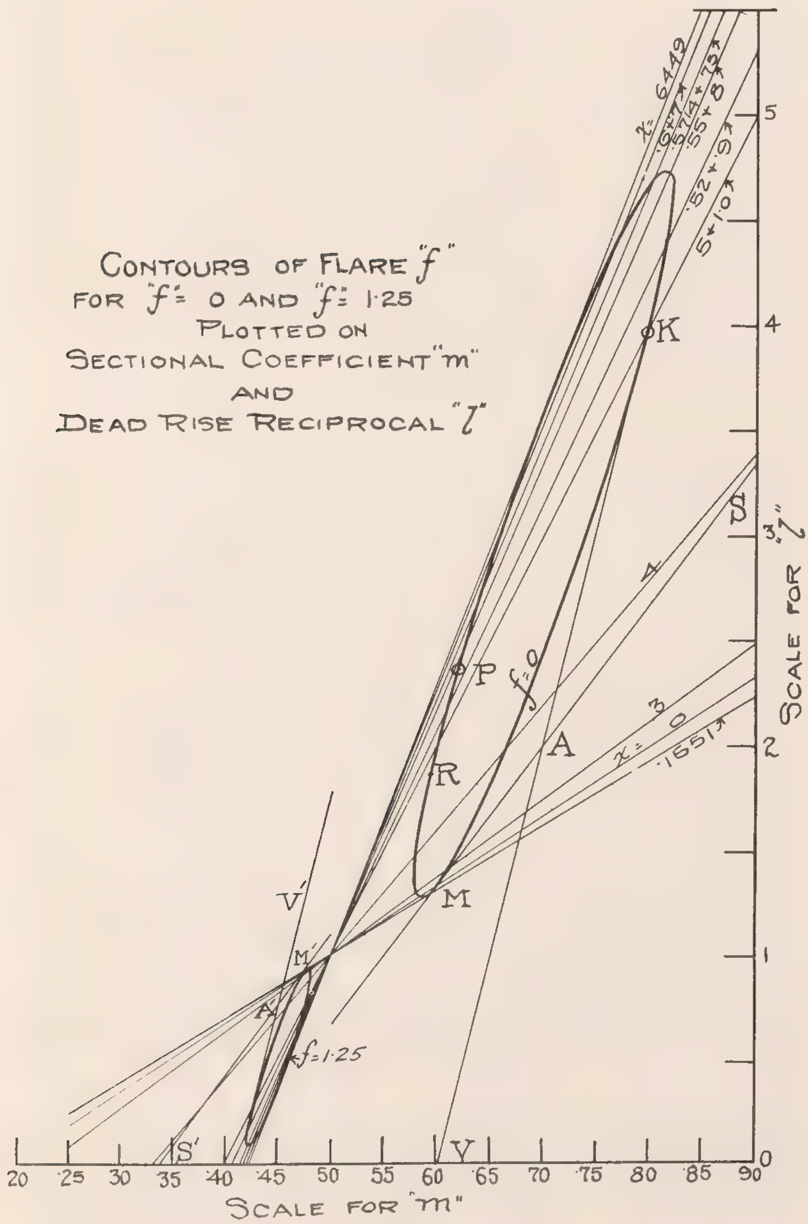

CONTOURS OF FLARE "f"
FOR "f" = 0 AND "f" = 1·25
PLOTTED ON
SECTIONAL COEFFICIENT "m"
AND
DEAD RISE RECIPROCAL "l"
SCALE FOR "l"
SCALE FOR "m"
K
P
R
M
A
S
V'
M'
S'
V
f=0
f=1·25

Fig. 13.

If we choose l and m inside of the ellipse $f = 0$, no tangent can be drawn to the ellipse and we will get no real points of inflection in the corresponding section.

If m and l are chosen for a point outside of the ellipse, there will be, in general, two real points of inflection, whose locations are given by the points of contact of the two tangents drawn from this point.

For our purposes it makes quite a difference whether a point of inflection is between $x = 0$, the keel, and $x = 1$, the water-line, or outside these limits. So let us look into the tangents to the ellipse when $x = 0$ and $x = 1$.

The general equation of all tangents is:

$$20\,(m - .5)\,(1 - 6x + 6x^2) - (l - 1)\,(3 - 12x + 10x^2) + (f - 1)\,(1 - 8x + 10x^2) = 0 \qquad (12)$$

By using (12), we can readily draw the tangents to any ellipse corresponding to points of inflection at $x = 0$, the keel, and $x = 1$, the water-line.

In Fig. 13 those tangents are drawn as indicated, the ellipse in Fig. 13 corresponding to $f = 0$. MAS is the tangent at the point M, corresponding to $x = 0$, and KAV the tangent at the point K, corresponding to $x = 1$.

For points in the angle opposite MAV, namely, KAS, we shall have a point of inflection in the vicinity of the water-line, a feature corresponding to a bottle-shaped section and not wanted, as a rule, with ship sections. For points within the angle SAV we shall have two points of inflection on the sections; and two points of inflection are not permissible, as a rule, for ship-shaped sections. For points within the angle KAM and outside of the ellipse, we shall have two points of inflection. These will be off the section for the area between the arc MK of the ellipse and the tangents AK, AM; and for the rest of the area within the angle KAM and outside of the ellipse, we shall have two points of inflection on the section.

Summing up, then, for sections of ordinary type, the available portions of Fig. 13, for $f = 0$, are within the angle MAV for hollow sections and the figure $AMRPKA$ for full sections.

Let us now consider the ellipse for a fine section, with $f =$ 1.25. This is the little ellipse to the left in Fig. 13.

For points within this ellipse there are no points of inflec-

tion, but the section is hollow from keel to water-line. For points without the ellipse there are two points of inflection, both or none of which may be between $x=0$ and $x=1$, or on the section. The remaining physical interpretation of the ellipse $f=1.25$ is very similar to that of the ellipse $f=0$.

Fig. 12 shows a series of ellipses and their tangents at $x=0$ and $x=1$, covering the range of f likely to be found in practice.

Since we do not care about points of inflection off the sections, the portions of the ellipses corresponding to these are omitted in Fig. 12, the locus for each value of f being made up of an elliptical part extending from $x=0$ to $x=1$ and the two straight lines tangent to the ellipse at the points $x=0$ and $x=1$.

The equations of these lines are readily obtained from (12).

For every locus of f we would like to know the point of inflection for any tangent. It would complicate the figure too much to put a scale of x around every ellipse, but by putting such a scale around the extreme border line of Fig. 12, as shown, a straight line drawn from the focus, $m=0.5$, $l=1$, to any point of an intermediate ellipse, and extended to the scale on either side, will give the x value for the point of intersection with the intermediate ellipse.

All ellipses lie between two bounding straight lines through $m=0.5$, $l=1$. These can readily be determined from equation (11).

We see from Fig. 12 that the fourth-power formula cannot be satisfactory for full sections. For such sections the side is usually plumb at the water-line, or $f=0$. The contour for $f=0$, in Fig. 12, shows that the maximum value of m which we can obtain without going outside the ellipse and, hence, introducing a point of inflection, is 0.8225.

Hyperbolic Sections.

For full sections to which the fourth-power formula is not adapted and for which, in fact, no parabolic formula will give satisfaction, the common hyperbola, properly treated, will be found quite satisfactory.

Referring to Fig. 14, let OAF be a hyperbola passing through the origin 0 and the point, A, ($x=1$, $y=1$) where the flare

is f. The section is on its side, MO being the draught and MA the half-beam.

Let BC be an inclined asymptote whose equation is of the form $y = ax + b$ and let DE be a vertical asymptote at a dis-

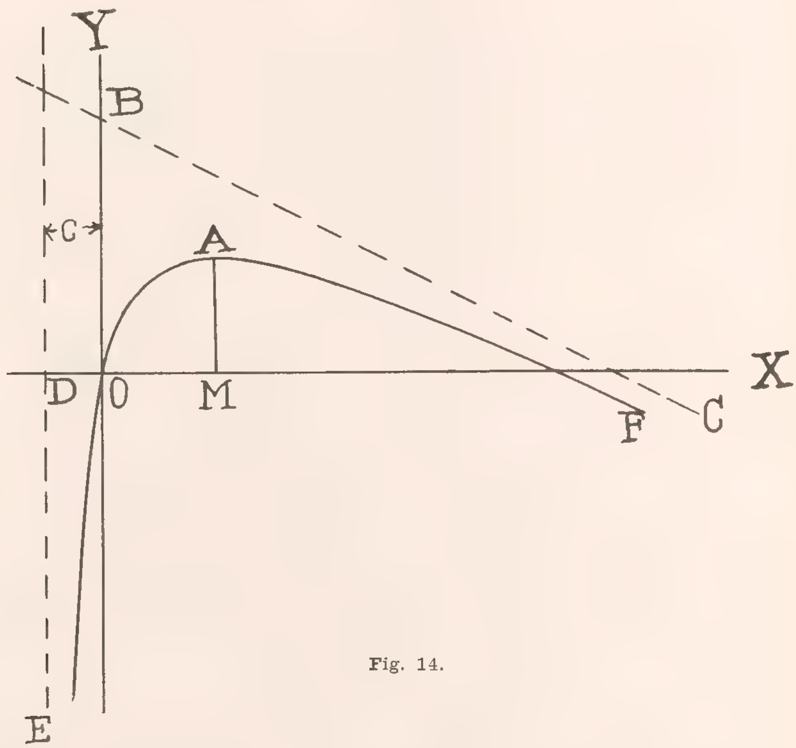


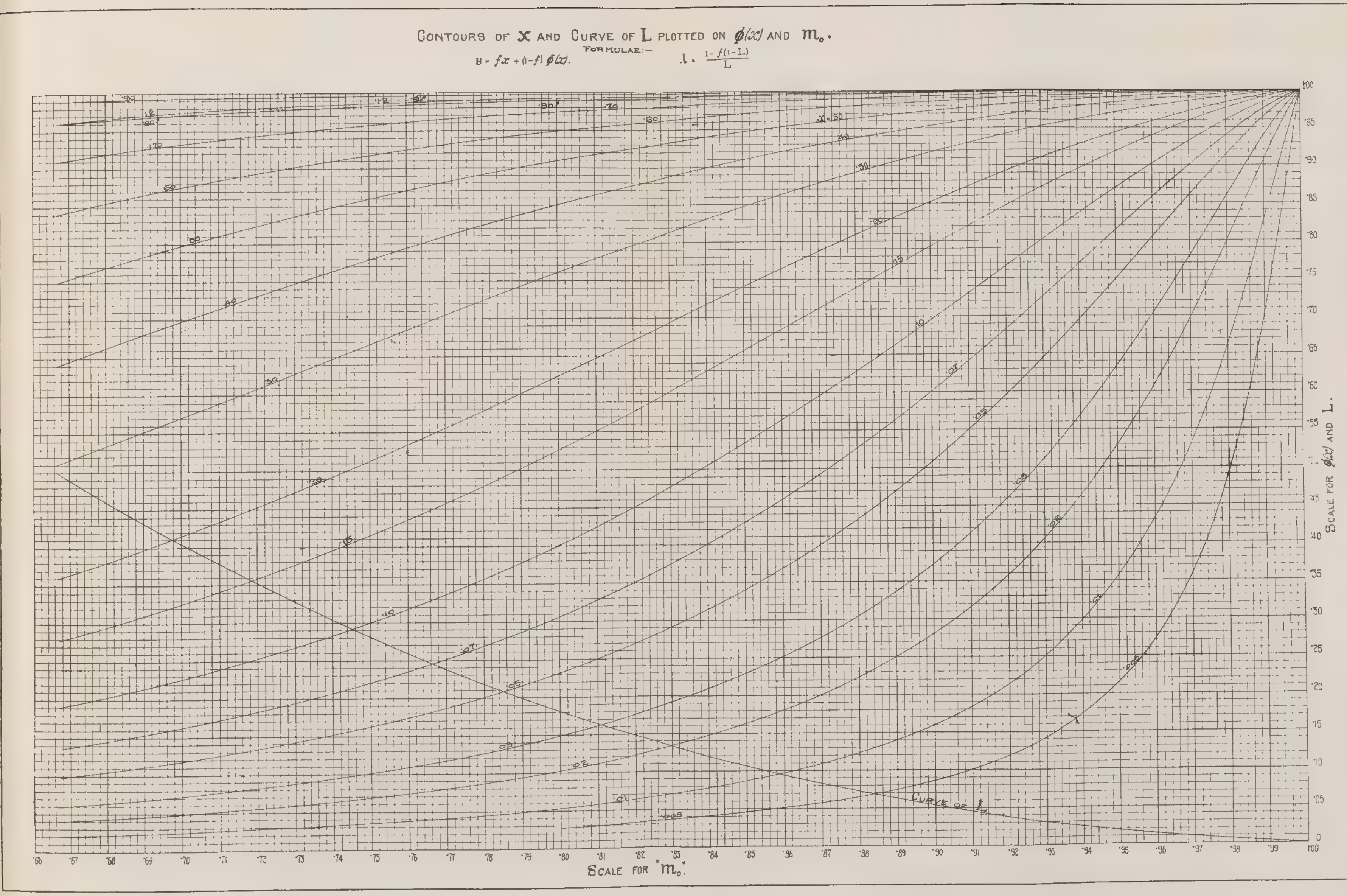
Fig. 14.

tance c to the left of the origin. The general equation of the hyperbola is then

$$y = ax + b - \frac{d}{x + c} \tag{1}$$

From the three conditions, that the hyperbola must pass through the origin, through the point $x = 1$, $y = 1$, and at that point have a flare f we obtain the values of a, b and d in terms of f and c, and substituting these values in the original equation, we obtain

$$y = fx + (1 - f)\,(1 + c)^2 \left[1 - \frac{c\,x}{(1 + c)^2} - \frac{c}{x + c}\right] \tag{2}$$



CONTOURS OF X AND CURVE OF L PLOTTED ON $\phi(x)$ AND m_o.
FORMULAE:–
$y = fx + (1-f)\,\phi(x)$.
$l = \frac{1-f(1-L)}{L}$
SCALE FOR "m_o".
SCALE FOR $\phi(x)$ AND L.
CURVE OF L.

Fig. 15.

Applying the further condition that the area of the section must be m, the coefficient of fineness, we have

$$m = \frac{f}{2} + (1-f)(1+c)^2 \left[1 - \frac{c}{2(1+c)^2} - c \log_e \frac{1+c}{c}\right] \qquad (3)$$

For full sections, an important case is when $f = 0$; and it so happens that the value of the sectional coefficient m when $f = 0$, is important.

If, now, we call m_0 the sectional coefficient when $f = 0$, we have, upon putting $f = 0$ in (3),

$$m_0 = (1+c)^2 - \frac{c}{2} - c(1+c)^2 \log_e \frac{1+c}{c} \qquad (4)$$

This equation gives us a relation between m_0 and c, so that we can express one in terms of the other by means of a curve.

Returning now to the general equation, we have if we write

$$\begin{aligned} \phi(x) &= (1+c)^2 \left[1 - \frac{cx}{(1+c)^2} - \frac{c}{x+c}\right] \\ y &= fx + (1-f)\,\phi(x) \end{aligned} \qquad (5)$$

Now we can contour $\phi\ (x)$ for various values of x, using values of c expressed in terms of m_0 from equation (4). Fig. 15 shows these contours for values of m_0 as abscissae, and Table III of "Calculations for Sections by Hyperbolic Formula" shows the detailed forms for calculations to obtain the co-ordinates y and x for any desired section.

We must start, in any case when using the hyperbolic formula, with values of m and f. The first thing to do then is to determine the corresponding m_0. Evidently, from equations (3) and (4), we have:

$$m_0 = \frac{m - \frac{f}{2}}{1 - f} \qquad (6)$$

Using the hyperbolic formula, we cannot fix arbitrarily the dead-rise. Fortunately, however, the dead-rises which naturally result from given values of m and f are suitable for the large coefficients to which only the hyperbolic formula is adapted.

We have now the hyperbolic formula for full sections and the fourth-power formula for fine sections. It is necessary to determine a method for shifting from one formula to another and the proper sectional coefficients, etc., at which to make the shift.

To be able to shift satisfactorily from one formula to another, we ought to be able to use either formula indifferently over a certain range of coefficients and constants. If we explore the closeness of agreement of the two formulae, by adopting identical values of m and f and applying to these values the fourth-power formula and the hyperbolic formula, we find that for values of m between 0.70 and 0.75 we can get practically identical sections from the two formulae. Then, as a general rule, we shift from the hyperbolic to the parabolic section for a coefficient of about 0.72. Since we can make the two formulae give practically identical sections at this point, the lines will bridge the gap between the last hyperbolic section and the first parabolic section with perfect fairness.

Since the dead-rise is not optional in the hyperbolic formula, we must be sure that the dead-rises of the parabolic sections fair in with those of the hyperbolic sections. This is an easy matter.

Application to the Preparation of a Set of Lines.

To illustrate the mathematical formulae, let us apply them to the design of a moderately fast merchant steamer, having the following dimensions:

Length	350 ft.	106.7 m.
Breadth	47.5 ft.	14.5 m.
Draft	16.5 ft.	5.03 m.
Displacement	4200 tons	4267 *tx*
Longitudinal coefficient	0.5826	
Midship-section coefficient	0.92	

A feature which is considered desirable, that of bulbous sections at the forefoot, is provided by giving the sectional area curve an ordinate, y_0, at *F.P.* equal to 2.5% of the area of the midship section. This square ending is subsequently lost by rounding off the corner with inappreciable change of displacement on ships of this character, which have no real section at *F.P.*, as is customary in some naval vessels. This changes the mathematical longitudinal coefficient of the fore body according to the formula $l_m = \frac{l - y_0}{1 - y_0} = \frac{0.5576}{0.975} = 0.5719$; that is the area of the rectangle $y_0 \times 1$ is taken away from both the original total area of the bow curve and its circumscribed rectangle.

Having proceeded so far, it now becomes necessary to choose

the constants to be used in formulae for both sectional area and load water-line curves.

The choice of constants t and a_1 for the different values of l and p must be governed according to experience and circumstances, such as speed, spaces required for steering gear and for cargo; and the values of p must be large enough to assure a water-line having sufficient moment of inertia to give a necessary, predetermined metacentric radius. It has been found that values of p for water-lines for fore bodies which will give the best sections when least resistance is desired are from 0.01 to 0.06 units greater than the longitudinal coefficients, the exact value being determined by the requirements. The larger this difference, the more pronounced is the V type of section, which generally is accompanied with higher resistance than where the difference is small and the sections are more of the U order.

The constants selected are as follows:

Sectional-area curves:						Load water-line curves:					
Bow			Stern			Bow			Stern		
lm	t	a_1	l	t	a_1	p	t	a_1	p	t	a_1
0.5719	0.80	—2.5	0.5826	0.5	0	0.64	1.10	0	0.75	2.5	0

Fig. 7 shows the four spots chosen for the four curves indicated above and marked *B.W.L.*, *S.W.L.*, *B.S.A.*, and *S.S.A.* Tangents from these spots to the a_1 contours corresponding show roughly where the points of inflection of the curves occur. All of these have a point of inflection between $x = 0.2$ and $x = 0.5$, except the after water-line, which has a point of inflection at each end. This tends to make the ends straight, that is, without curvature.

Tables I and II give calculations for ordinates of the water-lines and area curves. Of course, in these tables all constants are printed on the form—the amount of calculation being small. When we have plotted the sectional-area curve and the water-line, it is desirable to calculate systematically and record the coefficients, etc., for the various sections. This is done in Table IV. It will be noted that the calculation of m involves treating the half-breadth of keel in a similar manner as the area of *F.P.* was treated in the calculations for sectional-area curve of bow. Table IV also gives two columns of maximum and minimum

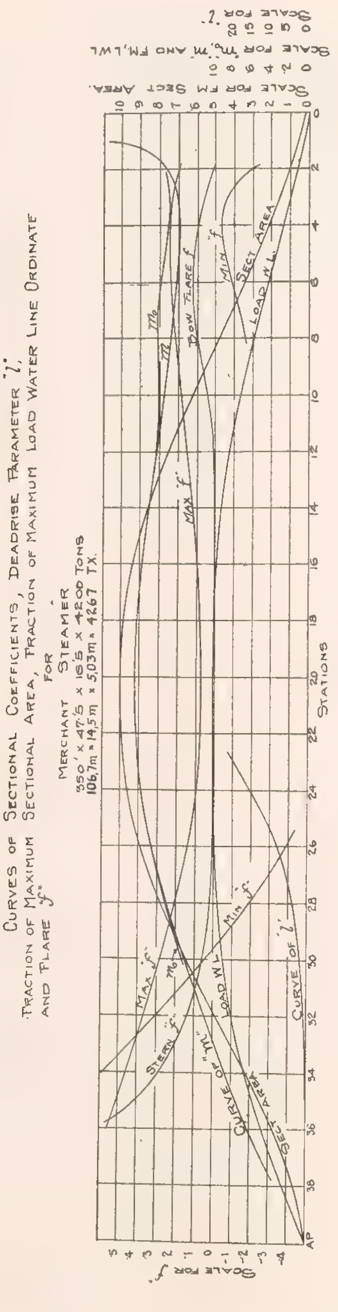

Curves of Sectional Coefficients, Deadrise Parameter 'l', Fraction of Maximum Sectional Area, Fraction of Maximum Load Water Line Ordinate and Flare 'f'
for
Merchant Steamer
350' x 47.5 x 18.5 x 4200 Tons
106.7m x 14.5m x 5.03m x 4267 TX.
Scale for FM Sect. Area.
Scale for m, m and FM, LWL
Scale for 'l'.
Scale for f
Stations
Bow Flare f
Sect. Area
Load W.L.
Max 'f'
Min 'f'
Stern 'f'
Curve of 'l'
Curve of 'm'
Load W.L.

Fig. 16.

flare, which show the limits between which one must stay in using hyperbolic sections. The curve of f depends largely upon the choice of water-line and sectional-area curves, but there remains considerable latitude for exercise of judgment and eye, having due regard to shape of topsides. The curve of f must be fair to assure fair lines.

Fig. 16 shows the curve of sectional area and the water-line plotted as fractions of maximum ordinates, also curves of coefficients m, m_0, f and l. We are now ready to take up the detailed calculations for the sections.

The ordinates for hyperbolic sections where $f = 0$ and $m = m_0$ are simply read off the draft contours of Fig. 15 for the corresponding m_0 and multiplied by the load water-line ordinate, B_2, for that station, remembering that the ordinates are to be laid off from the half-siding of keel line.

For hyperbolic sections where f is not zero, m_0 is calculated and these values used for taking off $\phi\ (x)$ from Fig. 15.

Table III shows calculations for both types of hyperbolic section.

Ordinarily, the change from hyperbolic to fourth-power sections occurs between $m_0 = 0.72$ and $m_0 = 0.66$. In the design in hand, the change is made between stations 30 and 32, station 30 being the last of the hyperbolic, and 32 the first of the fourth-power sections to be calculated. At station 30 we have $m_0 =$ 0.6713.

It is customary to calculate the dead-rise parameter of the hyperbolic sections from the formula

$$l = \frac{1 - f\ (1 - L)}{L},$$

L being taken from the curve of L shown in Fig. 15. The values of l are plotted over their respective stations, as shown on Fig. 16, and this line is extended aft until it becomes tangent to the base (deadwood begins) at some convenient station. The values of l so determined are used in conjunction with fair and usually increasing values of f for the determination, by the fourth-power formula, of the remaining sections. If these sections are not pleasing to the eye, the curves of l or f, or both, are modified, as desired, to give pleasing sections. We may even avoid deadwood entirely, in which case the l curve never reaches the base. It

may be remarked here that body plans that are most pleasing to the eye do not always make models having least resistance.

Table III shows calculations for sections by the parabolic formula. Fig. 17 shows the body plan drawn from the above resulting calculations and is strictly mathematical from station

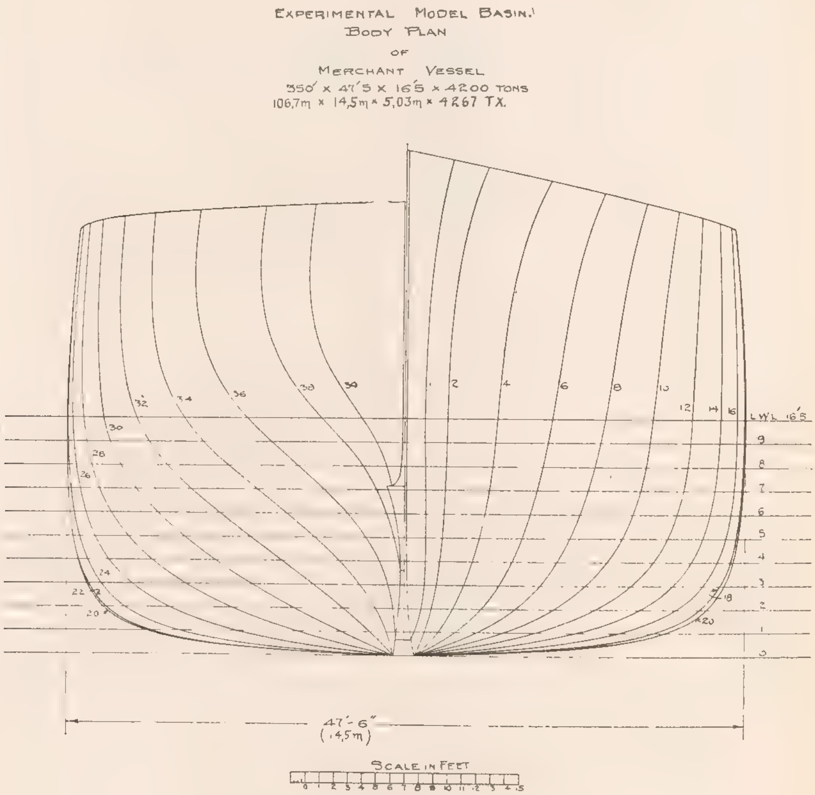


Fig. 17.

2 to station 34 and below the No. 10 water-line. (No. 36 was calculated, but altered slightly below W.L. 4.) Not a section has been planimetered or a spot avoided in drawing the water-lines in the half-breadth plan. The topsides are subject to the usual fairing.

The forms, as seen, provide for calculating a spot 0.2 of the draught above the water-line in order to make sure that the top sides leave the under-water body fairly, but, for ordinary forms, it is not usually necessary to calculate these spots.

APPENDIX II.

ROLLING EXPERIMENT ANALYSIS.

As a result of rolling experiments in still water, we usually have a record showing, upon time as a base, the angle of heel at any instant as the rolling dies away. In practice, the time of each roll is constant, within the limits of error of observations of usual accuracy. The most striking feature of such records is the regular and smooth declinations of the angles of maximum heel. Each such angle is smaller than its predecessor and larger than its successor. Moreover, the decrease in maximum heel between successive rolls becomes smaller as the rolls themselves diminish. It is obvious, of course, that the greater the resistance to rolling, the more rapidly the rolling diminishes; and the object of the present investigation is to determine methods of analysis of rolling records which will enable us, from a series of such records, to establish or confirm theoretical laws affecting rolling, and from the rolling records for a given ship, determine her proper coefficients or constants in rolling formulae.

While the records, as usually obtained, show the angle of heel at any time, we are concerned, primarily, with the successive maximum angles of heel; and rolling records are, therefore, usually reduced to curves where each maximum heel, as an ordinate, is plotted above its corresponding roll or swing, as abscissae, the abscissa value of a given roll or swing being proportional to the number of the roll or swing reckoned from some arbitrary initial roll or swing.

Mr. William Froude, the classical investigator in this field, called the curves of successive angles of extreme heel plotted over swing numbers, as abscissae, "extinction curves". Later English writers, notably, Mr. R. E. Froude (son of Mr. William Froude) have given the name "extinction curve" to a curve showing decrement of extreme angle between successive swings, and designated the curves which Mr. William Froude called "extinction curves" as "curves of declining angle". Following the later writers, I shall call them declining-angle curves, or, simply, "declining curves".

Theoretically, a declining-angle curve should show at each

point the extreme angle of roll. In practice, when rolling records are rectangular, the vertical ordinate at each instant shows the angle of heel, and it is customary to determine declining-angle curves by drawing curves tangent to the successive summits. This exaggerates slightly the angle, but the error is not material, unless the rolling records are for ships of great rolling resistance and extend to large angles.

There is a complication of nomenclature, which anyone who attempts to study the literature of the subject soon encounters.

English authors, Mr. William Froude included, designate a single swing from port to starboard as a roll, and, usually, the periods, etc., given by them refer to this roll. Continental authors are apt to consider a roll as covering the double swing, completing the cycle in rolling motion. On this question Mr. William Froude expressed himself, as quoted below, in "Naval Science", for 1872, page 418:

> "In treating curves of extinction in order to extract the information they contain, it has appeared convenient to take as a unit of count in the series, not a complete oscillation, say from starboard to port and back again, but the single swing from starboard to port, or *vice versa;* chiefly because, as the ship is a symmetrical figure, each of these separate steps in the progression represents alike an entire and complete dynamic operation, in which the ship starts from a position of momentary rest, passes through a position of maximum velocity, and arrives at a position of rest. The entire diagram represents a series of terms decreasing according to some law, and each individual swing represents the completion of one term in the series. The writer freely admits that the term 'Period' ought to be reserved as expressing the time occupied in performing the entire circuit of oscillation 'out and back again, through the starting point, with motion in the same direction as at starting'; and this he would term P. But he hopes he will be tolerated if he prefers to use here the simple symbol T to denote the smaller individuality of the single swing, instead of being obliged to have constant recourse to its fractional equivalent $\frac{P}{2}$."

In order to avoid confusion due to difference in meaning given to the term "roll", I will follow the hint in the quotation above from Mr. Froude and call "the single swing from starboard to port, or vice versa", not a roll but a swing. Then there should be no confusion.

There is another matter where care must be used in nomenclature. In any mathematical treatment of rolling, it is convenient to measure angles always from the vertical as zero; but when the expression "angle of roll" or "rolling angle" is used, it is very apt to be applied to the angle rolled through from port to starboard, or vice versa, which is confusing. By always speaking of the deflection from the vertical as a "heel" and sticking to the expression "angle of heel", a source of confusion is eliminated.

Let us now go into the mathematics of extinction of rolling in still water, following briefly Mr. Wm. Froude's methods, which are fully set forth by him in "Naval Science", for 1872, beginning at page 411.

Let θ denote angle of heel.

Let Θ denote extreme angle of heel, and Θ_s this angle for swing number s. Then Θ is the declining-curve ordinate.

Let W denote weight of ship or model.

Let m denote metacentric height of ship or model, in feet. Then at the instant of rest at the end of a swing, s, we have, as usual,

$$\text{Energy stored} = \frac{Wm}{2}\,\Theta^2{}_s$$

At the end of the next swing

$$\text{Energy stored} = \frac{Wm}{2}\,\Theta^2{}_{s+1}$$

Then

$$\text{Loss of energy during swing} = \frac{Wm}{2}\,(\Theta^2{}_s - \Theta^2{}_{s+1})$$

$$= \frac{Wm}{2}\,(\Theta_s + \Theta_{s+1})\,(\Theta_s - \Theta_{s+1}) = \frac{Wm}{2}\,(\Theta_s + \Theta_{s+1})\,\Delta\,\Theta$$

Now if R denotes resistance to rolling, expressed as a couple, when the inclination is θ we have also

$$\text{Loss of energy per swing} = \int R\,d\theta,$$

the integration extending over the swing.

We know, also, that for one swing $\Delta s = 1$, and that Θ decreases as s increases.

Then

$$-\frac{\Delta\,\Theta}{\Delta\,s} = \frac{\int R\,d\,\theta}{W_m \dfrac{\Theta_s + \Theta_{s+1}}{2}}$$

Then passing to the limit we have with sufficient approximation

$$-\frac{d\,\Theta}{d\,s} = \frac{\int R\,d\,\theta}{W_m\,\Theta}$$

Here we must suppose that Θ is an extreme heel and $\int R d\theta$ is the integration of R with respect to θ through ½ swing before and ½ swing after the extreme inclination Θ. So we need next to investigate $\int R d\theta$. While we do not know in advance the value of R in terms of θ, we do know that it depends primarily upon the angular velocity. Then denote R by one or more terms of the form $R = k_n \left(\frac{d\,\theta}{d\,t}\right)^n$. We know, too, that the motion of the ship is practically harmonic. This being the case, if we denote by S the swing period, or ½ the cyclic period of roll, we have

$$\theta = \Theta \sin \frac{\pi\,t}{S}$$

$$\frac{d\,\theta}{d\,t} = \Theta \frac{\pi}{S} \cos \frac{\pi\,t}{S}$$

We also have

$$d\,\theta = \Theta \cos \frac{\pi\,t}{S}\, d\left(\frac{\pi\,t}{S}\right)$$

Then we may write

$$R = k_n \left(\Theta \frac{\pi}{S} \cos \frac{\pi\,t}{S} \right)^n + k_p \left(\Theta \frac{\pi}{S} \cos \frac{\pi\,t}{S} \right)^p + \text{other terms of same form.}$$

Whence

$$R\,d\,\theta = k_n \left(\Theta \frac{\pi}{S} \cos \frac{\pi\,t}{S} \right)^n \Theta \cos \frac{\pi\,t}{S}\, d\left(\frac{\pi\,t}{S}\right)$$

$$+ k_p \left(\Theta \frac{\pi}{S} \cos\left(\frac{\pi\,t}{S}\right) \right)^p \Theta \cos \frac{\pi\,t}{S}\, d\left(\frac{\pi\,t}{S}\right) + \ldots\ldots$$

$$\int R\,d\,\theta = k_n\, \Theta^{n+1} \left(\frac{\pi}{S}\right)^n \int \cos^{n+1} \frac{\pi\,t}{S}\, d\left(\frac{\pi\,t}{S}\right)$$

$$+ k_p \Theta^{p+1} \left(\frac{\pi}{S}\right)^p \int \cos^{p+1} \frac{\pi\,t}{S}\, d\left(\frac{\pi\,t}{S}\right)$$

Then

$$-\frac{d\,\Theta}{d\,s}=\frac{\int R\,d\,\theta}{W_m\,\Theta}$$

$$=\frac{k_n\,\Theta^n\left(\frac{\pi}{S}\right)^n\int\cos^{n+1}\frac{\pi\,t}{S}\,d\left(\frac{\pi\,t}{S}\right)+k_p\,\Theta^p\left(\frac{\pi}{S}\right)^p\int\cos^{p+1}\frac{\pi\,t}{S}\,d\left(\frac{\pi\,t}{S}\right)}{W_m}$$

If we assume that there is only one term involved and $n=2$, or the resistance varies simply as the square of the angular velocity, we have

$$-\frac{d\,\Theta}{d\,s}=\frac{4}{3}\pi^2\,k_2\,\frac{\Theta^2}{W_m\,S^2}$$

This is readily integrable, giving us as the equation of the extinction curve upon this basis,

$$s=\frac{3}{4}\,\frac{W_m\,S^2}{\pi^2\,k_2}\left(\frac{1}{\Theta}-\frac{1}{\Theta_o}\right)$$

or

$$s=\frac{1}{b}\left(\frac{1}{\Theta}-\frac{1}{\Theta_o}\right)$$

where s is swing number measured from the swing where the heel was Θ_o and b is a constant coefficient.

If we assume that there are two terms involved, one varying as the first power of the angular velocity, and the other as the second, we have

$$-\frac{d\,\Theta}{d\,s}=\frac{\pi^2}{W_m\,S^2}\left(k_1\frac{S\Theta}{2}+\frac{4}{3}k_2\Theta^2\right)$$

whence, upon integration, we obtain

$$s=\frac{2\,W_m\,S}{k_1\,\pi^2}\log_e\frac{\frac{4}{3}k_2+\frac{k_1\,S}{2\,\Theta}}{\frac{4}{3}k_2+\frac{k_1\,S}{2\Theta_o}}=\frac{1}{a}\log_e\frac{b+\frac{a}{\Theta}}{b+\frac{a}{\Theta_o}}$$

when b is the same coefficient as before and a is another constant coefficient.

These are the formulae of Bertin and Froude, respectively. To determine how closely they apply, the simplest plan is to use the differential equations above, which when reduced, are, for Bertin $-\frac{d\,\Theta}{d\,s}=b\,\Theta^2$ and for Froude $-\frac{d\,\Theta}{d\,s}=a\,\Theta+b\,\Theta^2$. We need to know, in any case, $-\frac{d\,\Theta}{d\,s}$. From the declining-angle curve this can be determined graphically. The graphic method, however, is not very accurate, and it will be found in practice

more convenient and more accurate to use an algebraic method. If we have five successive ordinates of any curve, namely, T_{-2} T_{-1} T_0 T_1 and T_2 the horizontal spacing being l, then for the point on the curve corresponding to the middle ordinate, T_0, we have for the determination of the tangent

$$\frac{dy}{dx} = \frac{1}{12\,l}\left\{8\,(T_1 - T_{-1}) - (T_2 - T_{-2})\right\}$$

In using Bertin's formula, once we have determined the values of $-\frac{d\Theta}{d\,s}$, we simply need to take these values at successive points and determine the corresponding values of b from the formula. It will be found that these values vary materially in the length of declining-angle curves extending over any range. For Froude's formula it is a very simple matter to make a focal diagram. We have $-\frac{d\Theta}{d\,s} = a\,\Theta + b\,\Theta^2$. For each value of Θ and $\frac{d\Theta}{d\,s}$, this gives a linear relation between a and b and can be represented by a straight line on axes of a and b. There will be a separate straight line for each point taken on the declining curve. If all of these straight lines pass through a common point or focus, evidently the values of a and b at this point will accurately characterize the declining curve in the formula

$$s = \frac{1}{a}\log_e \frac{b + \frac{a}{\Theta}}{b + \frac{a}{\Theta_0}}$$

but it is found in practice that the a and b lines thus obtained do not make a satisfactory focus for declining curves extending over large angles. The values of a and b for the intersection of any two lines would give the declining curve passing through the two corresponding points, and if the points are fairly close together, the portions of the declining curves between them are fairly well represented; but investigation of a large number of declining curves of models showed that the formula does not give a close approximation for declining curves extending over a range as large as 20 degrees.

Suppose, now, we undertake a somewhat more general investigation, and assume that the resistance to rolling at any point is expressed by the formula $R = K\left(\Theta\,\frac{\pi}{S}\mathrm{Cos}\,\frac{\pi\,t}{S}\right)^n$ where K

and n may have any value. This leads us, following previous methods, to the equation

$$-\frac{d\,\Theta}{d\,s}=\frac{K}{Wm}\left(\frac{\pi}{S}\right)^n \Theta n \int_o^\pi \mathrm{Cos}^{n+1}\frac{\pi\,t}{S}\,d\left(\frac{\pi\,t}{S}\right)$$

The integral $\int_o^\pi \mathrm{Cos}^{n+1}\frac{\pi\,t}{S}\,d\left(\frac{\pi\,t}{S}\right)$, which we may call I, is known for integral values of n, and can be readily determined by plotting curves and integrating them mechanically for intermediate or fractional values of n. The equation thus reduces to

$$-\frac{d\,\Theta}{d\,s}=\frac{K}{Wm}\left(\frac{\pi}{S}\right)^n \Theta^n I$$

The values of I over a range sufficient for practical purposes are given below:

n	I
0.	2.00
0.25	1.863
0.50	1.749
0.75	1.653
1.0	1.571
1.5	1.437
2.	1.333
3.	1.178
4.	1.067
5.	0.982

In any particular case, we know W, m and S for the ship or model. From the declining curve, we can get Θ and $\frac{d\,\Theta}{d\,s}$, and if we assume a value of n, everything is known or readily determined on both sides of the equation, including K. Then for any point characterized by Θ we can assume a series of values of n, obtain the corresponding values of K and draw a curve K and n. If we draw a series of such curves for a number of such points, and find that they intersect at or very close to a common focus, the focal values of K and n characterize and accurately represent the declining curve. Unfortunately, the lines involved in this case are not straight lines, and if we wish to plot them over a wide range of n, it is necessary to use a sliding scale for K, which is very much less for large values of n than for small values of n. This, however, does not affect the accuracy of the results, but means only a little more trouble in determining the diagrams.

Fig. 18 shows a diagram in n and $x^n L$, L being a function of K, where there is a good focus when $n = 1.5$. Not all declining curves will give such a good focus, but experience with the analysis of a number of declining curves seems to indicate that if we assume that resistance to rolling varies as the $1\frac{1}{2}$ power of the angular velocity, we get closer agreement with actual declining curves than is given by either Froude's assumption or Bertin's assumption.

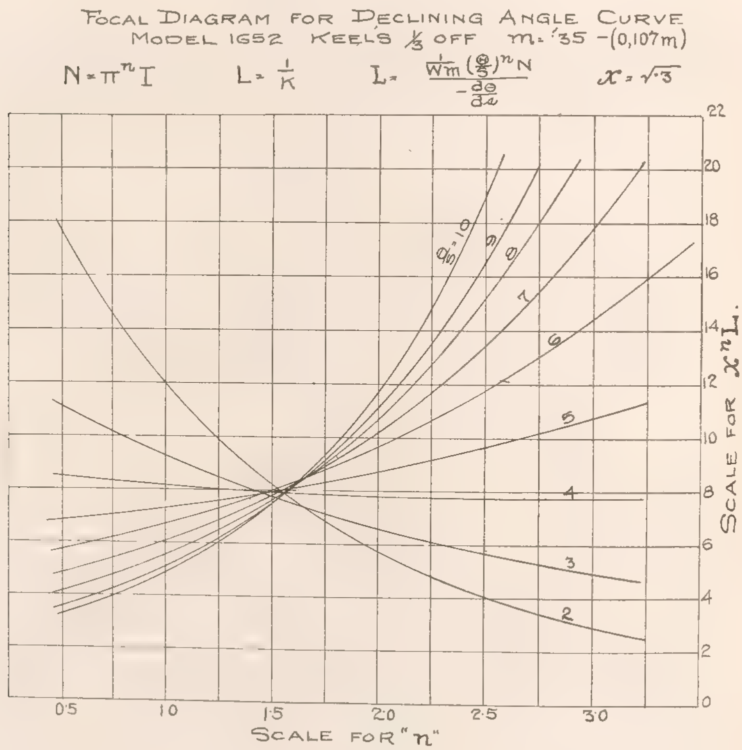


Fig. 18.

Pending the determination of formulae representing with scientific accuracy the laws of rolling in still water, there is need for some method of expressing simply and with reasonable accuracy the relative resistance to rolling of ships. A very simple plan is to use the decrease of heel in a single swing, or the roll decrement, at a standard heel. Thus if 10° is the standard

heel chosen and the roll decrement from 10° is 0.8 of a degree, we may characterize the resistance to rolling of the vessel by saying that she has a roll decrement of 8 per cent at 10 degrees. When dealing with models, we may use an angle of 10 degrees, or even more, as the standard at which we take decrement; but full-sized ships cannot be artificially rolled to a heel of 10 degrees, as a rule, and for them the standard heel must be much less—say 3 or 4 degrees.

DISCUSSION

Admiral M. Kondo,* Imperial Japanese Navy, wrote that with reference to the use of mathematical formulae for obtaining the lines of new design, he had been for years in search of some such method, or methods, for rapidly determining the lines to conform with certain required data and was very glad that the author had succeeded in getting formulae sufficiently simple for the purpose. He thought they would be very useful in fixing the shapes of water lines and the areas of sections, but for the shapes of sections feared they might not be always applicable, since very often such shapes were controlled by other factors than those enumerated by the author. For instance, the consideration of dock accommodation might affect the form of the midship section and make it more or less irregular in shape. In any case, he thought it a capital device for the first approximation and felt very grateful towards the author for suggesting it. Admiral Kondo.

In regard to variation of friction with temperature, he had had similar experiences himself, and while not prepared to give actual figures, could safely say that he quite agreed with the author on that point.

* Ministry of Marine, Tokyo, Japan.

Paper No. 197

OCEAN FREIGHTERS.

By

ERNEST H. RIGG, M. I. N. A., Mem. S. N. A. & M. E.
Camden, N. J., U. S. A.

When approached by the Committee of Management to write on this subject, I felt considerable hesitation on account of the magnitude of the field; after reading the very clear suggestions accompanying the list of topics, I felt considerably reassured, because things were so well divided up, and those who wrote could not fail to understand what was expected of them.

At the risk of getting a little into the theoretical field (Topic No. 1), I feel that a few remarks are in order here concerning that side of the freighter's design. During the last ten years considerable progress has been made in design proper; after warships and fast merchant ships had received for years almost undivided attention from the experimental tanks, the full cargo boat has begun to come into its own; both here and abroad a great deal of work has been and is being done, and naval architects who keep informed are now in possession of considerable valuable literature on this subject; the coal economies to be realized are enough to pay for this experimental work over and over again, for one average cargo vessel a 5% coal saving means about $2,000 a year in round figures, and for a fleet of ten such vessels, $20,000; how far $20,000 would go in experimental work needs no comment! Spread a saving like that over a national merchant marine and consider also that the passenger liners and special types share the upkeep of the same experimental basin, and the conservation of fuel that is being effected will be realized at once. In warships also, equally great savings are being made. In addition to the best lines for

a given fullness, we are also working to get the economical relationship of dimensions, speed, fullness and length of voyage, each to the other.

Still on the theoretical side of the subject, we must note increased attention to questions of stability and its problems. Instruments that are practicable are gradually being introduced and used for enabling the ship's officers to keep tab on the loading and stability. The relationship between bulkhead subdivision and stability hardly comes within the scope of this topic.

A prominent mention must be made of the total and sweeping revision of classification rules during our 10-year period. Lloyd's Register and Bureau Veritas have issued new rules that swept aside at one stroke the old and clumsy tables; these rules are based on sound theoretical, as well as practical, ground, and the benefit to shipping is difficult to over-estimate. Our American Bureau is a little late in meeting these conditions, though I believe it also has undertaken some work along these lines.

The influence of the classification societies in cargo vessel construction is bound to be considerable; the profession is indebted to them for much assistance in the investigation of structural strength, both main and local; they form a link between builder and owner that should be of value to both; the other link between owner and underwriter is of as great importance.

Credit must also be given to Lloyd's Register for the early freeboard work they did, prior to loading being regulated by statute in different countries; this subject is still a live one and will be referred to later.

When on the subject of classification, the pioneer work on modern ship construction and scantlings done by the British Corporation of Glasgow, is well known to all shipbuilders versed in the literature of our profession.

It will be seen from the bibliography below, that most of the great maritime countries have a strong classification society of their own; these societies perform an undeniably valuable service in the formation of a good merchant marine; the question of classification has been discussed pro and con, for many years, though perhaps not so much lately; yet I feel sure that a

strong society enjoying the confidence of builders, owners and underwriters, is an asset of great value in the upbuilding and maintenance of a merchant marine worthy of confidence. As is only natural, Lloyd's Register must be conceded premier position, for besides being strong in their own country, they also are so well represented the world over, that they do considerable work in all countries, and especially so in the United States. With the present (March, 1915) demand for cargo ships, the formation of a New York Committee of Lloyd's Register, similar to those of Liverpool and Glasgow, appears to the writer to be worthy of consideration.

The multiplication of societies, in the face of the present tendency towards international shipping regulations, does not seem desirable, but just as the two districts mentioned above felt the desirability and need of local control, so the increasing volume of business in America suggests the same need. The opening of the Panama Canal and the broadening of our prospects would seem to be a fitting time to consider a New York Committee, using Lloyd's standard rules for ocean ships and corresponding ones for the Great Lakes, as a basis of proved value. Whether such an arrangement would work well, is, perhaps, open to debate; recent events appear to argue that it would. There is probably a large number who would favor an independent American body; it would not be easy to establish or organize such a society, also it would, without doubt, be necessary to draw on the excellent work and the extensive experience of the older societies. It is to be regretted that the American Bureau is not the strong organization that it might be; modern requirements are exacting, and a large staff is necessary to give the yards the necessary service; few modern ships are straight rule types, and technical knowledge of an advanced order is required in very considerable quantity, as well as quality.

A definite standard of strength is a necessity and the registry society is the natural repository of the accumulated experience of ship builders and owners. In addition, structural stresses in ships are difficult of accurate ascertainment, simply because the sea is the sea, and not on account of any lack of technical ability on the part of designers of ships. This diffi-

culty does not exist to the same extent in other engineering lines.

Structural materials for ship building have benefitted by the general advance in metallurgy, as well as by the improvements in rolled sections consequent on standardization of shapes. As regards rolled shapes for shipbuilding, the work of the British Engineering Standards Committee deserves special mention. Improvements and increases in channels and bulb angles in our own country come along slowly; as regards plain angles, we have all the selection that is needed, but there is decided room for improvement in channels and bulbs, some larger zees also would be acceptable. Some work looking to an increase of selection and improvement of section has been done through the American Society for Testing Materials, but it rather needs concerted action on the part of those interested, to get these rolls adopted and made.

Structural standards are not well adapted to ship construction, although shipbuilders are at times compelled to use them; this does not apply, of course, to plain angles.

The possibilities in the way of reduced riveting following the improvement of shapes are considerable; lesser first cost, combined with easier conditions of upkeep, should appeal to the owner. The American shipbuilder is undoubtedly handicapped in this matter when compared with his European rival. There is good reason to believe that the present activity in shipbuilding in our country will lead to more sections being rolled in American mills.

Safety of life at sea claims only a limited reference under this topic. Among the chief advances in this respect must be noted the increasing adoption of the British Board of Trade Freeboard Rules, which prevent the overloading evils so prevalent in times past. The European War held up important work in this direction, and when the International Load Line Conference is able to proceed with its work, rules for loading may be expected which all leading maritime states will subscribe to; the vexed question of deck loads will be an important one at this Conference, as well as the load line.

Bulkhead sub-division can only be applied to cargo steamers in a limited way, after seeing to it that the collision bulk-

head is up to its possible responsibility; also that the after peak and shaft tunnel are secure, together with watertight isolation of the propelling machinery; such other bulkheads as can be fitted are those that are necessary for strength only. In special ships, such as oil tankers, practical unsinkability is approached very closely; in coal and ore boats also, a good deal can be done, but large, open holds are primary necessities in general freighters, both liners and tramps.

The idea of enough lifeboats on each side of the vessel, to take care of all hands, is an excellent one, and should be universal; doubling the boatage for some 30 to 40 men is very moderate in cost compared with the loss of even one half of those men; in fact, it seems out of place to mention the cost when such a remedy is as easy to apply as it is on ocean freighters.

Fire alarm and extinguishing systems are on the market, and are being fitted on some ships, in addition to the steam lines and fire hose required by law. Wireless telegraphy, submarine signals and other navigational aids should be mentioned here though their description comes under another topic.

Another point that must be mentioned in our 10-year review is the improvement in accommodations for officers and crew. The ship is the sailor's home, and there is no good reason why he should not have facilities for living in a self-respecting style; berths limited to two in tier, separate messrooms, showers and good washing facilities should be universal. All these things, combined with improved ventilating and heating arrangements, are to be noted in recent ships. The cold storage of food, together with the increase in available canned goods also contribute to the sailor's well-being.

Ocean freighters can be divided into two main divisions, cargo liners and tramps; the first division can be further divided into types such as oil carriers, bulk freighters, general freighters, refrigerator ships. It is, perhaps, outside the province of this paper to discuss the question of freight liner versus freight tramps. The liner comes more to the front as time goes on, but at present a revival in tramp construction is to be noted. This in itself is a good sign for shipping prosperity.

Freight liners are subject to very much the same rules as passenger liners. Each service develops and improves its own type, whereas in tramps, the tendency to standardization can be noted. This standardization is natural when the circumstances are considered; the ships are to be generally useful, the larger the ship the more cheaply the freight is carried, but harbor depths, wharves, etc., in the smaller ports soon limit sizes, and thus we are forced to a compromise, which can be called a 7000-ton deadweight carrier, 22′6″ (6.9 m) draft, and of about 360′0″ (110.0 m) x 50′0″ (15.2 m) x 29′6″ (9.0 m) moulded dimensions.

Statistics give the following average dimensions for cargo vessels:

Item	Year 1890		Year 1900		Year 1910	
Length in feet	285	(87.0 m)	312	(95.0 m)	340	(104.0 m)
Breadth in feet	37	(11.3 m)	41½	(12.6 m)	46	(14.0 m)
Draft in feet	19¼	(5.9 m)	20½	(6.2 m)	21½	(6.5 m)

The advance in dimensions is steady and without doubt will so continue; dredging operations continue the world over, and all harbor authorities are anxious to provide the best facilities. It is safe to say that the shipbuilder can easily keep pace with terminal improvements, and in many cases ships have been built with a margin of 2 to 3 feet (0.6 to 0.9 m) in their loading ability, in order to be ready to take advantage of port improvements not completed at the time of building.

Turning more particularly to types, one which has been developed to a great extent recently is the single deck cargo steamer. Pillars and hold beams are now eliminated entirely, if desired, from all cargo spaces; arches, transverse and longitudinal, carry the deck and tie the structure together. Single deckers up to 34′ 6″ (10.5 m) moulded depth, are being built to receive the highest class. Needless to say, the side framing is getting up to 15″ (0.38 m) channel for such ships. Another comparatively modern idea is in constructing double bottoms with a solid plate floor on every third frame only, except at the ends and under machinery.

The omission of all side stringers also should be noted, compensation for which is readily made. In vessels of great

depth, it is scarcely advisable to fit no stringers on account of the danger of the frames tripping, but the classification tabular number can well be reduced.

Joggling frames and beams are now very general; flush decks made by joggling down the beams and fitting joggled plating are much cheaper than flush decks with planed and fitted edge laps, equally efficient for trucking, and better from the riveting and structural point of view.

Twin masts and king posts are a modern development to be noted. Shorter booms and better working conditions generally result where they are adopted.

Wide spaced framing is adopted in many ships, i. e., the rule spacing laid down by the classification societies is frequently increased several inches. Frames and shell have to be strengthened, of course, and no saving in weight results, but the number of parts to be handled is materially reduced.

Wide spaced pillaring is, generally speaking, a modern development. Lloyd's first gave definite tables whereby the forest of small pillars could be replaced by more widely spaced and larger pillars, with girders under the decks to transmit the loads to these pillars. No weight saving is to be made, but greatly increased facilities for stowage result.

Wide spaced pillars had been in vogue for some years before the classification printed rules gave tables for the same.

Topside tank ships have come to the front, and for vessels which have to make long oversea voyages in ballast, they, together with the usual double bottom, furnish a most excellent distribution of the ballast weight; particularly in bulk trade ships, where the space under the deck is apt to be left empty, the topside tank is well worth its cost. As a safety arrangement also they have points, the two sides, from the load waterline up, constituting a protection in the event of collision.

It is to be noted that the turret and trunk steamer have not lasted as general types; their construction takes place only very occasionally. The same may be said of whale-backers; though a Great Lake type, they are used on the ocean, but not to any great or growing extent.

There is one great advance to be noted in our period which is worthy of special mention, and that is the revival of the

longitudinally framed ship, for which credit must be given to Mr. J. W. Isherwood. The adaptation of longitudinal construction to merchant steamers has been of singular advantage in several types, notably in oil steamers. The system is ideal for oil steamers and all long and shallow types. For bulk and general freighters the advantage also is considerable, but is not so marked as for oil tankers. In all types there is an appreciable saving in weight. Costs usually compare favorably after the first ship at each yard has been built and experience gained. Torpedo-boat destroyers and light cruisers also can well be built on this system.

The advantages of the system are less structural weight, reduced vibration, greater longitudinal strength, and greater capacity in some instances; the disadvantages are transverses sticking out into holds, operative in some trades, and holding up coal or other bulk cargoes on the longitudinals. It is interesting to note that the total gross tonnage built and building to the system is nearly 1,500,000, which speaks for itself, as the period covered is under ten years.

The carriage of cooled and refrigerated cargoes has made considerable progress in the last ten years; fruit is carried by regular liners in vast quantities from the warmer to the colder climates, particularly bananas. The carrying of chilled and frozen meats has reached proportions undreamed of ten years ago, so much so that the carrying of live cattle has very largely ceased.

As an indication of the growth of the frozen meat trade, the following figures are of interest:

Live stock imports into Great Britain: Cattle from 642,747 head in 1890 decreased to 138,387 in 1910. Sheep from 1,065,470 head in 1895, dwindled to 183,084 in 1905 and practically to nothing in 1910.

The imports of frozen and chilled beef have increased from 200,000 tons in 1900, to 488,000 in 1910, in Great Britain alone.

Mutton and lamb imports have gone up from 152,500 tons in 1900 to 263,000 tons in 1910.

These figures serve to show the change that has come over the methods of carrying meat from the places of origin to those of consumption.

The shipping engaged in this trade is of a high quality, for none other could deliver the products to market in fit shape for human food.

The growth of the cooled fruit trade is no less remarkable; bananas have become cheap and staple articles of food, available the year round in places where only a short while ago they were comparative luxuries; the same may be said of oranges.

Whilst on this subject, the effect of cold storage on the menus of large passenger liners may be noted. Passengers now enjoy fully as good and as varied food aboard ship as people do on shore, and what is true for the liner is no less true for the cargo ship. All ships have at least an ice box, and those for long voyages have refrigerating machinery and rooms for provisions.

The various types of refrigerating machinery scarcely come within the scope of this paper; marine types have been developed to keep abreast of land types.

A kindred subject is that of canned goods; vegetables of all sorts can now be carried, and that old enemy, scurvy, is scarcely heard of any more; even milk is evaporated and carried in cans aboard ships. Such strides in the methods of keeping and carrying food deserve our attention, as being important factors in ship development. Ships not only have the usual galley, but if the voyage be long enough, a bakery also is fitted and fresh bread is available for all. The extending use of bitumastic compounds calls for a note here; the preserving quality of these materials has gained for them a considerable market in spite of a somewhat high initial cost. In all parts of the ship that are difficult of access, under machinery where corrosion is assisted by the heat inseparable from such places, they have been found invaluable.

While it cannot be said that radio telegraphy has influenced cargo ship design, yet at the same time the installation of such apparatus is rapidly becoming universal, and indeed is now compulsory on all vessels carrying fifty or more persons; the greater ease of transmitting orders from agent or owner needs no comment.

The elimination of wood decks is noticeable; plain steel

decks are the thing in freight spaces, and many substitutes for wood in living spaces are on the market.

The Panama Canal has already begun to influence ocean freighter design, and vessels for long voyages and of large dimensions are being constructed in more or less modest numbers. The American Hawaiian Steamship Company's vessels are probably the best type of large ocean carriers built for canal trade. The latest vessels of this fleet are worthy of a little study.

The ships are 430′ 0″ (131.0 m) by 53′ 6″ (16.3 m) by 39′ 6″ (12.0 m) to the shelter deck and carry 9,000 tons total deadweight on 28′ 0″ (8.5 m) draft. They have power for 12 knots at sea, and have limited passenger accommodations. They are fitted with all the decks their depth will allow, and are arranged for oil fuel, single screw drive.

Fast fruiters of large dimensions have also been the subject of numerous designs, their speed having been based on the average speed of freight across the continent. This will necessitate a sea speed in the neighborhood of 16 knots, which is quite practicable as far as the ship and machinery are concerned, and is, in fact, the general speed for a combined fruiter and passenger ship in the West Indian trade. It can be said that many designers are at work on ships for the canal trade, and that definite types will be evolved when conditions are more settled. Radical departures from standard types do not appear to be imminent; it is safe to say, however, that the ships will be both larger and faster than those in general use on either coast.

Large lumber steamers for canal trade are also under consideration. One design the writer has seen, prepared by Messrs. G. W. and J. S. Dickie, contemplates a vessel 440′ 0″ (134.0 m) long, 12 knots sea speed and 5,000,000 board feet of lumber; oil fuel and with ballasting arrangements such as will enable partial loads, including deck loads, to be safely carried, whilst collecting cargo from several points for the trip through the canal. A long trunk and elevated cargo handling gear, are features of the design.

The large amounts of money being spent on terminal facilities, dealt with under another topic, are bound to have an in-

creasing effect on ship design. Take the Bush Terminal at New York as an instance. The writer calls several instances to mind where cargo ports had to be a fixed distance from the bows of a ship to suit openings in shed sides; it did not matter whether they came abreast the other breaks in the structure or not, a fine, new ship had to be butchered to suit some ramshackle old wharf that would not last five minutes in any fire that amounted to anything. These quaint old relics in the way of wharves are rapidly being replaced in all our big harbors. Wharves will, in future, be so arranged as to give reasonable latitude in ship arrangement. The mere fact that development is being allowed for will automatically take care of the ship's interest.

Rapidity of despatch becomes more important the larger the ship is; also, the larger the ship, the more self-sustaining she becomes in the matter of minor repairs. It is a sign of the times to be noted that the ship's force are asked to do less and less while in port, at any rate among the large lines, so that they can have reasonable freedom in port and get home for just as long a time as under former conditions, with the longer wait in port. The gain due to a quick turn around each trip, might easily mean two or three voyages more per year.

The improvement in crew's quarters aboard ship has been noticeable of late years, and this is by no means confined to the ships of any one nation. This is one of the handicaps of American shipping that is being removed by the other fellow grading up, instead of ourselves grading down.

Lumber steamers are in a class by themselves; they should be specially designed and proportioned for their trade, and when such is the case, deck loads are by no means the menace they are in an ordinary steamer used to carry lumber cargo. Besides being of extra beam, the ship is built with a strengthened main deck and special bulwarks; these precautions, together with lashing chains, enable deck cargoes up to 14′ 0″ (4.3 m) high, to be safely carried. Trouble is apt to arise when ordinary cargo steamers, designed for a hold cargo only, load lumber to their statutory (European) freeboard and carry a deck load to do it. The International Load Line Conference will have the question of the freeboard and deck loads of lumber steamers to consider. The technical press has lately contained consider-

able comment on this vexed subject. The fact that many lumber steamers are operated with oil fuel, makes security of deck load doubly necessary. The solution is minute sub-division of oil tanks in both directions, so that it is not possible to get large free surface losses in stability.

The deep centre line tank adopted by Mr. E. S. Hough, meets this point admirably, though open to the defect of large calking surfaces exposed to damage, as compared with ordinary deep tanks. As compared with ordinary double bottom tanks, the deep centerline tank is considerably less liable to damage and possesses other advantages to compensate for the large riveted areas.

It would appear to be altogether just to allow properly designed lumber steamers to load deeper than ordinary cargo steamers, on account of the buoyancy of the cargo. The beam of the vessel is a fundamental consideration in this, and in the present freeboard regulations, beam is only casually mentioned. It is safe to say that the problem is by no means unsolvable, and that with the vast amount of data recently prepared, a way will be found that will be just to all concerned, owners, underwriters and crew.

An interesting solution of the lumber steamer problem is that afforded by the "William O'Brien", a vessel designed by Mr. E. S. Hough, and built at the New York Shipbuilding Company's yards in Camden, New Jersey. The deck load is carried in a light superstructure over the three forward holds, the fourth being open, as usual. The superstructure protects the dry and finished products from the sea, and in addition, the high sides extend the range of stability. The lumber is lifted aboard in heavy iron straps, making packages four feet square, which are used again to unload at the other end of the trip. This vessel is served by special overhead loading and unloading plant, and consequently does not carry her own gear. The high sides would necessitate an elevated control platform for operating the winches in an ordinary, self-discharging lumber steamer.

This superstructure, if fitted all the way between poop and forecastle, would have marked advantages to compensate for its extra first cost, namely:

1. Protects cargo from loss by wave action.
2. Lower insurance rates for under deck cargo.
3. Stronger ship due to great depth of girder.
4. Enables large hatches to be more easily obtained due to height above sea.
5. Enables other cargoes to be carried to full capacity of the ship, protected from the weather.

These advantages apply to a vessel carrying wet, unfinished lumber, as well as one carrying dry, finished cargoes.

Turning now to motive power, the last ten years have witnessed greater changes in this field than can readily be grasped. Ten years ago it is safe to say that the well-nigh universal method of cargo ship propulsion was by means of compound or triple expansion engines, with an occasional quadruple expansion engine here and there. Scotch boilers were in undisputed possession of the field, and were coal fired; this can be said because paddle wheels were not applied to ocean cargo steamers during our period. What do we find today? The whole marine engineering world is considering several alternatives. Steam turbines have made wonderful strides, motor ships are quite common, and cargo steamers are being driven by high speed turbines, mechanically geared down to normal propeller speeds. Electric reduction gear is being seriously proposed, likewise hydraulic gearing, with a view to using turbines for prime movers. Scotch boilers still hold the field for ocean cargo ships, except in isolated cases, but oil fuel is being used in many routes where the supply is assured, coal no longer being, to all intents and purposes, universal.

Reciprocating engines are still the principal type of motive power, but geared turbines are making a splendid start, being capable of, roughly, a knot greater speed on the same fuel consumption in an average ship.

Motor ships, particularly when twin screws are adopted, are making progress for low powers only. Electric drive has been tried in a few cases, but has hardly emerged from the purely experimental stage for cargo ships.

Of the several alternatives the geared turbine looks the most promising for vessels of this type, particularly since improved methods of gear cutting have been adopted.

The application of mechanical gearing and steam turbines for the propulsion of cargo boats is rapidly increasing.

The number of vessels now at sea and under construction is in excess of thirty.

Reports from the vessels in service state that there is no appreciable wear on the pinion teeth after being in constant operation upwards of two years.

The saving in economy of fuel consumption for a single screw installation averages about 15%, and in case of a twin screw installation a saving in fuel consumption will be at least 20% over reciprocating machinery.

Another point to be considered in applications of this type is the question of saving in weight of machinery and engine room space. A geared turbine installation effects a saving in the machinery weights averaging 10%, and in many cases one or two frame spaces can be saved in the length of the engine room.

Attention may well be directed here to the renewed efforts to solve propeller problems; this has been rendered necessary mainly by the high rotative speeds asked for by turbine and internal combustion engineers; the experimental model basin, combined with careful trial trips, is the key to the solution of propeller problems. In this country particular credit is due to Chief Constructor D. W. Taylor, and Captain C. W. Dyson, both of the Navy; great credit is also due to Professor H. C. Sadler, of Ann Arbor University, for his published and other research work on both full and fine models.

In Europe also much work has been done in this field. Mention should be made of the National Physical Laboratory in England, where valuable experimental tank work on cargo and other merchant ship models has been done under Mr. G. S. Baker.

Machinery and propellers hardly come within the scope of this paper, so are merely touched upon to record the benefits received by even the humble ten-knot tramp from their progress.

''Coal per diem'' is keenly watched by owners, and it behooves every cargo ship builder not to let his competitors get ahead of him in the matter of economy of propulsion.

To keep up with the adoption of internal combustion propelling engines, attention is being given to reducing the number of steam auxiliaries, though the exhaust gases from the main engines can be used for keeping steam on a donkey boiler. Particular attention is directed to the hydro-electric steering gear now being fitted on quite a number of ships. An oil-fired donkey boiler and steam winches for port use offer a good method for cargo and anchor handling purposes. Motor driven pumps are common, and so on, down the list.

More extended and detailed reference to machinery does not belong to this topic.

In a general paper such as this is, I feel that I am in order in drawing attention to some of the handicaps under which builders and owners of cargo vessels work, particularly builders, as I scarcely feel competent to speak for owners. Of recent years an increasing number of patent ship constructions have appeared on the scene; as I remember things twenty years ago, builders built ships and adapted construction to circumstances with a far freer hand than is now possible; nowadays you cannot do the most obvious thing in designing a ship on combined scientific and practical lines, without getting a letter from somebody enclosing a copy of his patent. Doubtless many patents are valid and deserving of recognition, but on the other hand, one does not have to search the literature of shipbuilding far to find the same thing in an almost identical form, in only too many cases.

We have lately been favored with a host of suggestions from every direction in regard to the means for increasing the safety of life at sea, as was only proper after such accidents as the "Titanic", "Empress of Ireland" and other recent cases.

The internationalisation of basic requirements has been perceptibly advanced and is to be welcomed by builders, owners, underwriters, crews and public, as tending towards a rational solution of the intricate problems the subject presents, and away from the evils of panic and sectional legislation.

In America we suffer from the practical inability of builders to specialize. This is an age of specialization, and no time or space need be taken here to argue its advantages. I do not wish to imply that each yard should build only one type, but

such a mixture as battleships, light-ships, carfloats, barges, destroyers, colliers, oil tankers and passenger steamers going on at one and the same time, is difficult to handle efficiently. A large total volume of business is the only solution to that problem, however.

Another point which is a handicap to a greater or lesser extent, dependent on circumstances, is that of yard standards, both as to practice in general and fittings in particular. If a yard has a good reputation, and it cannot have that without some experience and length of life to its credit, there are numerous instances where owners can save time and money by adopting builders' standards, unless it can be shown that they are not suitable to their particular trade.

With regard to our navigational laws and the changes which will have to be made before our merchant marine can be adequately revived, much has been written of late. The European War has brought home very forcibly the shortage of vessels of American Registry; several causes combined to withdraw European cargo ships; freight rates went up and vessels too old for ordinary use, that had lain for years and months tied up to the docks, were pressed into service; also ships of American ownership and foreign registry were changed over to our flag. With all these increases the supply did not meet the demand, and we have perforce to be content with the mail, passenger and cargo service that Britain, France, Italy and Scandinavia and our own few ships, find time and convenience to give us. The large German tonnage was withdrawn absolutely with the first gun of the war.

A short and very readable description of the situation is to be found in the 1914 Presidential Address before the Society of Naval Architects in New York.

As regards the present status of ocean cargo ships, it is evident that we are at the beginning of a period of increased activity (written March, 1915); large ships are the rule, notably so in oil tankers, in which longitudinal framing is firmly established. All eyes are turned towards new types of propelling machinery and considerable economies of propulsion are confidently looked forward to, and have already been realized

in some instances, notably in the case of geared turbines and of motor ships of low power.

The increased attention given to safety of life at sea will probably result in cargo vessels being required to carry boats enough for all hands on each side of the ship, this being law in Great Britain already. Subdivision as effective as in passenger ships is not practicable, except in a few cases, such as oil tankers and bulk carriers that are unloaded by ample overhead gear.

The submarine tactics at present (March, 1915) being employed in European waters against merchant steamers will scarcely have any permanent effect on cargo ship design; they merely furnish a temporary argument for closer bulkheads.

In conclusion, I wish to express the hope that these lines will be found of interest to my shipbuilding brethren, and of some value to all interested in the art.

In compiling the annexed bibliography, I have been struck with the tremendous amount of literature there is available, and with the difficulty of in any way making a complete list of valuable data bearing on this subject, without devoting an amount of time to the matter, which I have not at my disposal.

The idea of a series of references is excellent, and the Congress authorities deserve great credit for having adopted it. No attempt has been made to cover the general literature of naval architecture, merely that bearing on cargo ship construction has been tabulated.

I regret that my limited knowledge of the languages and means of access to the great store of information contained in French, German, Italian and Scandinavian literature prevents a listing of works in those languages.

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DISCUSSION

Mr. W. A. Dobson,* Mem. Soc. N. A. & M. E., wrote that the author's remarks about an American Committee on Lloyd's Register of Shipping were well worth serious consideration. The benefits to the shipbuilder from having such a committee in America would be so great that it seemed possible that the difficulties in the way could be overcome. As all the larger shipbuilding yards on the Atlantic Coast, except one, are located on the Delaware River, or south of it, it would be appropriate and would best serve the interests of the shipbuilders to have this Committee located in Philadelphia, just as the Committee for the Clyde is located in Glasgow. Mr. Dobson.

As an American with interest in American institutions, it seemed to him remarkable, in view of the number of vessels being constructed in this country, that the American Registration Society had not so revised its rules and strengthened its force as to retain the full confidence

*Naval Architect, Wm. Cramp & Sons' S. & E. B. Co., Philadelphia, Pa.

Mr. Dobson. of the ship owners, and make an American registration society paramount. There did not seem to be any difficulty in bringing this about if proper consideration were given to the matter.

He said that, when working out a design, it was natural to obtain the end desired by construction or framing that gave the necessary strength and stiffness with the least weight and cost, or perhaps with the element of cost alone considered. He had found it more than annoying to come up against some patented construction, which in the particular case was the logical and practical solution of the problem. He doubted very much if many of these patents would hold under a test of law.

Mr. French. **Mr. James French,**§ Mem. Inst. Naval Arch., London, said that he would be glad to recommend the establishment of an American Committee of Lloyd's Register as suggested by the author.

Mr. French wrote that he was glad to find the work of Lloyd's Register so much appreciated. He noted with satisfaction that the author, as a result of his experience, discouraged the multiplication of Classification Societies and classification standards.

From extensive experience in America and Great Britain, Mr. French agreed with the author that the setting up of different standards of safety in ship construction was much to be deprecated, alike in the interests of shipbuilders, ship owners and underwriters.

He stated that the function of Lloyd's Register remains today, as in the past, the safeguarding of the interests of underwriters who cover the risks of ship owner and merchant. The Society is well equipped, through its broadly representative Committee and its highly scientific and practical staff, to deal in a sympathetic spirit with the changing conditions which the enterprise of shipbuilders and engineers is continually evolving.

§ Glasgow, Scotland.

Paper No. 198

RECENT DEVELOPMENTS IN JAPANESE SHIP-BUILDING.

By

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PART I. GENERAL REMARKS.

Although the introduction of European methods of ship-building in Japan dates from the later fifties, it was not until after the Chinese war of 1894-5 that Japan really began to take active steps in promoting her shipbuilding industry. The only merchant ships, worthy of special mention, built before that war were the "Kosuge Maru", a wooden screw steamer of 1500 tons gross, completed in 1884, and the "Suma Maru" a steel screw steamer of 1600 tons gross, launched during the war, both at the Mitsubishi Works, Nagasaki. The ships then built at home were mostly small wooden vessels less than 500 tons gross; for the building of large iron or steel vessels, all the shipyards were still incomplete in their equipments and limited in their experience, while the building materials had to be imported from abroad; higher prices and late deliveries were the natural consequences.

At the time of the Chinese war, ships available for war purposes were not numerous and the Government and private owners bought a large number of second-hand steamers to meet the military as well as commercial requirements.

After the victorious ending of the war, the commerce and industry of the country expanded enormously and the sphere of navigation was greatly enlarged; the building of large merchant ships at home was thus greatly fostered. The Japanese government became aware of the necessity of giving considerable encouragement to merchant ship-building, and bills for the sub-

vention of navigation and ship-building were passed in the diet. The Acts were promulgated in March 1896, to be in force for 15 years.

They showed a remarkable result; new routes for Europe, America and Australia were soon started; trades along the coasts of Oriental countries were rapidly extended; and there was a great expansion of shipping. As to ship-building, subsidy was given to iron or steel ships above 700 tons gross, and ships built under the Act grew gradually both in number and size. The first ship of importance, which formed an epoch in the history of Japanese merchant ship-building, was the "Hitachi Maru" of 6170 tons gross, built at the Mitsubishi Dockyards, Nagasaki, in 1898. She was to the order of the Nippon Yusen Kaisha, which at the same time had built in Great Britain several steamers of similar size for its European service; her dimensions were as follows:

Length between perpendiculars	443 ft. 0 in. (135.1 m.)
Breadth moulded	49 ft. 2 ins. (15 m.)
Depth moulded	34 ft. 6 ins. (10.515 m.)
Dead weight on 25 ft. 9 ins. (7.85 m.) draught	7700 tons
Cargo capacity at 40 cu. ft. (1.133 cu. m.) per ton	7780 tons
Gross tonnage	6172 tons
Speed	14.43 knots
I.H.P.	4083

No. of passengers—1st-class, 29; 2nd-class, 20; steerage, 124.

She was of unprecedented size at that time, and it seemed rather a bold undertaking for the inexperienced builders; models and drawings necessary for producing a duplicate vessel of those built on the Clyde were supplied by the Clyde builders, under special arrangement made with the owners. The ship proved in every way very successful, and orders for large ships began to be placed with the home shipyards. While Japanese shipping and ship-building were making steady progress, the war with Russia broke out in 1904, during which a large number of second-hand steamers were again imported in order to meet urgent want for both military and commercial services. The following table shows the rate of increase of Japanese merchant ships during these periods.

Period	Merchant Ships Existing (above 1000 tons)		Increase		Merchant Ships (above 1000 tons) built at home during these periods	
	No.	G. T.	No.	G. T.	No.	G. T.
End of 1893	56	295,748				
			70	169,948	1	1,562
End of 1896	126	265,696				
			71	246,074	30	80,041
End of 1903	197	511,770				
			124	314,933	21	47,304
End of 1906	321	826,703				

As can be seen from the above table, merchant tonnage in Japan rapidly increased in the two wars, and towards this tonnage home builders supplied quite an insignificant part.

After the peace with Russia was established, and as a result of fever for public enterprises, important shipping companies laid out extensive schemes for the expansion of their fleets by new construction at home, thus marking another epoch in the ship-building industry of Japan. The most important additions during this period were 3 trans-Pacific liners of 13,400 tons gross and 20 knots speed, "Tenyo", "Chiyo" and "Shinyo Maru"—all built at the Mitsubishi Dockyards in 1908-11.

Although the effect of the application of the Shipbuilding Encouragement Acts has been very remarkable in promoting the rapid growth of Japanese ship-building, still the industry is not yet independent of Government assistance, nor can Japanese ship-builders yet compete on equal terms with those of other maritime nations. Before the enforcement of the Encouragement Act of 1896 expired, the revised act to protect the industry by giving the subsidy for ships over 1000 tons gross was passed by the Diet of 1909, to be in force for a period of another 10 years from 1910.

The number of ships built under the Subsidy Acts up to the present, is as given in Tables I and II; and the diagrams in Plate I help to show the progress of the ship-building industry in Japan.

For some time most of the ships built at home were for the subsidized routes and were equipped with more or less accommodation for passengers, while ships used for freighting business on irregular trips were second-hand steamers imported from abroad.

But the principal ship owners have for some time past realized the advantages of owning up-to-date cargo steamers, in order to enter into free competition with foreign-built tramp steamers.

DIAGRAM SHOWING THE TONNAGE OF VESSELS ADDED TO THE REGISTER EACH YEAR.

SHADED PORTION — PURCHASED FROM ABROAD.
PLAIN PORTION — BUILT AT HOME

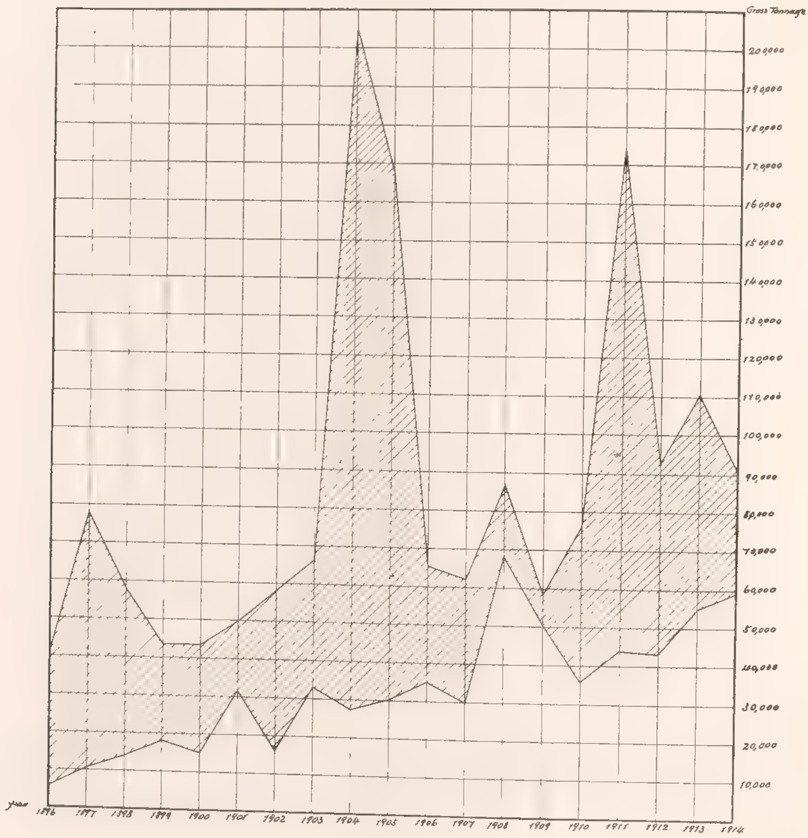

Plate I.

This has led to the present condition, in which all ship-builders are trying their best to produce cheap cargo ships, while all sorts of new improvements and innovations in the art of ship-building have been imported. As yet these ship-yards have had little experience in building cargo ships of very simple construction, and there has been little inducement, in the past, to seek for such experience.

In other maritime countries, the ship-building industry is roughly divided into two sections, one dealing with large numbers of medium- or small-sized cargo ships of almost standardized pattern, while the other does the better class of work appertaining to large passenger or war vessels. But in Japan there has been practically none of the former class, because of very limited demands for such vessels, and all sorts of work has been done in the ship-yards, for which purpose they have all been equipped similar to those building the latter class of vessel. They were originally laid out with the object of doing the maximum amount of work upon any ship, purchasing from outside sources only raw materials and proprietary or patented articles. This has been quite necessary, for although Japanese manufactures are rapidly improving, those of ship-building and engineering accessories have yet been in their infancy, and could not be depended upon for the best class of work. Thus, all of these works are very extensive and elaborately fitted out, even compared with the first-class works in Europe and America; this has involved big outlay at the start and heavy establishment charges throughout. It is not surprising that these large ship-yards meet with difficulty when placing themselves in competition for the class of work usually done by the small ones. Then again the lack of ship-building materials and the lower efficiency of labour in spite of low wages have also handicapped the sound development of cargo-ship building. These facts account naturally for the higher price and late delivery of home-built cargo ships; the ship-building subsidy now given is based upon the bare freight and dues paid upon the imported materials, while for many inherent wants mentioned above there are no provisions.

But the present war in Europe has brought about considerable change in this state of matters. Owing to the scarcity of tonnage all over the world, Japanese cargo-ship owners are now showing unprecedented activity. Not only are their steamers fully employed to fill up the vacancies left in Oriental waters by the withdrawal of German and Austrian vessels and the shortage of British and Norwegian tonnage, but they have also instituted new services to nearly all parts of the world. Then again, there are big demands for freight carriers, especially those of larger tonnage, in the European market, for which a good many Japan-

ese cargo ships have been sold or chartered. Out of 1,567,000 tons of merchant steamers (above 1000 tons gross) now* possessed by Japanese owners, about 811,000 tons are engaged in regular service, while 756,000 tons are tramp steamers engaged in trade of an irregular nature, of which about one-fifth—a little over 140,000 tons—are now* on European, South and North American and Australian services. The want of steam tonnage in Japan has always been, till now, filled up by importing second-hand steamers from abroad, but there being no possible means at present of getting ships, whether old or new, from outside sources, Japanese owners have decided to order ships from home builders. Thus all the important ship-builders in Japan are fully

Name of Ship-yards	Number and Gross Tonnage of Merchant Vessels		
	Under Construction (May 1915)	Ordered (May 1915)	Total
Mitsubishi Works, Nagasaki	1—9600	4—7300 2—3700	7— 46,200
" " Kobe		1—1800 2—5200	3— 12,400
Kawasaki Dockyard, Kobe	1—9600 1—2600	3—7300 2—4400 1—3000 1—1700	9— 47,600
Osaka Iron Works	1—2600	12—3200 6—7300 1—5000 1—1100	21— 90,900
Uraga Dock Co.		5—2200	5— 11,000
Ono Shipyard		1—3200 1—1300	2— 4,500
Fujinagata Shipyard		1—2000	1— 2,000
Harima Shipbuilding Co.		2—1100	2— 2,200
Grand Total			50—216,800†

* May 1915.

†Increased in Nov. 1915 to about 70 vessels of 310,000 tons gross.

occupied, indeed almost saturated with orders for new construction. The table on the preceding page will indicate how busy all builders will be for the coming year or two, and it is quite interesting that all the ships now ordered are cargo vessels intended for free service, viz, without receiving subsidy, a condition rare in the case of home-built steamers in the past.

The case is quite exceptional, and it is doubtful whether Japanese owners will still require new ships after the present abnormal rise in the freight market has been leveled, and whether Japanese builders can compete on even terms with foreign builders when the state of things in Europe becomes more settled.

But one thing is certain, that the present activity in ship-building at home has been a very good opportunity for the accumulation of experience in such class of work, and the promotion of allied industries, such as manufacture of auxiliary machinery, ship fittings, etc. All of these mean the supply of some of the inherent wants which have handicapped the development of the Japanese ship-building industry.

Turning to Naval construction, similar instances can be cited of its rapid growth. The naval dockyard at Yokosuka was started as early as 1864, when the Japanese Government was being supplied with her first war vessels from the Dutch Government. The first war-ship built at Yokosuka was the "Seiki", a wooden gunboat of 900 tons displacement, launched in 1875; she may be considered as the pioneer of all the war ships built in Japan. This was followed by a good many gunboats and small cruisers, wood, composite, iron and steel. The "Hashidate", a steel protected cruiser of 4300 tons displacement, launched from Yokosuka Naval Dockyard in 1891, was the largest and most powerful war-ship built in Japan before the war with China.

The navy yards at Kure and Sasebo were commenced in 1889 and 1890 respectively, and were equipped with ship-building and repairing facilities. But it was not until just before the Chinese war that these places became of any great importance.

After the Chinese war, Japan embarked on an enormous naval extension programme, with a total expenditure of about \$102,000,000, extending over 10 years. The ships built under this programme, with those already building or contracted for at the time of the Chinese war, consisted of 6 battle-ships, 6

armoured cruisers, 10 small cruisers and despatch vessels, 3 gunboats, 20 torpedo-boat destroyers and 63 torpedo boats. On this occasion, the navy yards were still destitute in both their experience and equipments. Thus, in carrying out the programme, Japan had to depend on foreign assistance, her own share in the new construction being only 10 small cruisers and destroyers, about one-tenth in the total displacement. During this period, however, all navy yards were extended and equipped with the most modern appliances, capable of building hull, machinery and accessories of the heaviest warships; an arsenal and steel foundry for manufacturing guns and armour plates were added to the Kure Navy Yard.

During the Russian War, the "Tsukuba", an armoured cruiser of 13,750 tons displacement, was laid down in the Kure Navy Yard in 1904. She was the first armoured vessel built in Japan and marked a new epoch in the history of naval construction. She was, moreover, the first vessel of cruiser class to carry battle-ship armament, and the most powerful armoured cruiser in the world at the time, really the forerunner of the new type of warships known as "Battle Cruisers".

Soon afterwards the "Satsuma", the first battle-ship built in Japan, was laid down at Yokosuka in May 1905, five months earlier than the "Dreadnought"; she was the heaviest battle-ship in the world at the time of her launch. These were soon followed by many others of similar types—3 battle-ships "Aki", "Settsu" and "Kawachi", the two latter being larger and more powerful than the "Aki"; and 3 battle cruisers, "Ikoma", "Kurama" and "Ibuki", the two latter being larger and more powerful than the "Ikoma".

The first destroyers built in Japan were the "Haruna" and her three sisters, 375-tons displacement and 30-knots speed, laid down at Yokosuka Navy Yard in 1902, just before the Russian War. They proved very successful and 35 boats of this class were built after the outbreak of the war; of these, 15 were constructed at private yards. Two ocean-going destroyers of 1150 tons displacement and two medium-sized destroyers of 600 tons displacement were also built at home.

The principal private ship-yards in Japan capable of turning out the heaviest war-ships complete with their machinery, have been invited during late years to assist in naval construc-

T A B L E I.

SHOWING THE NUMBER AND GROSS TONNAGE OF VESSELS BUILT UNDER THE SHIPBUILDING ENCOURAGEMENT ACT. YEARS 1897 - 1915.

Gross Tonnage	700 -1000		1000-2000		2000-3000		3000-4000		5000-6000		6000-7000		7000-8000		8000-9000		9000-10,000		Above 10,000		T o t a l	
Year	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage
1897	1	727	--	---	--	---	--	---	--	---	--	---	--	---	--	---	--	---	--	---	1	727
1898	--	---	1	1,519	--	---	--	---	--	---	1	6,172	--	---	--	---	--	---	--	---	2	7,691
1899	--	---	2	3,411	--	---	--	---	--	---	1	6,309	--	---	--	---	--	---	--	---	3	9,720
1900	--	---	2	3,144	2	4,489	--	---	--	---	--	---	--	---	--	---	--	---	--	---	4	7,633
1901	2	1,447	3	3,815	2	4,787	--	---	--	---	2	12,620	--	---	--	---	--	---	--	---	9	22,669
1902	1	724	3	4,215	2	5,569	--	---	--	---	1	6,443	--	---	--	---	--	---	--	---	7	16,951
1903	3	2,615	2	3,167	2	4,470	--	---	2	10,606	--	---	--	---	--	---	--	---	--	---	9	20,858
1904	5	3,921	2	2,255	1	2,029	--	---	--	---	--	---	1	7,463	--	---	--	---	--	---	9	15,668
1905	2	1,523	5	7,680	2	4,226	--	---	--	---	--	---	--	---	--	---	--	---	--	---	9	13,429
1906	4	3,109	7	9,382	--	---	1	3,588	--	---	1	6,715	--	---	--	---	--	---	--	---	13	22,794
1907	5	3,964	1	1,808	2	5,017	2	7,176	--	---	--	---	--	---	1	8,523	--	---	2	26,880	13	53,368
1908	2	1,660	1	1,811	--	---	1	3,204	--	---	--	---	--	---	4	34,043	--	---	--	---	8	40,718
1909	2	1,785	--	---	--	---	1	3,272	--	---	3	18,542	--	---	1	8,512	1	9,287	--	---	8	41,398
1910	1	757	--	---	--	---	--	---	--	---	2	12,120	--	---	--	---	--	---	--	---	3	12,877
1911	--	---	4	4,495	--	---	--	---	--	---	1	6,063	--	---	--	---	--	---	1	13,377	6	23,935
1912	--	---	1	1,393	1	2,933	3	9,820	--	---	2	13,037	--	---	--	---	--	---	--	---	7	27,183
1913	--	---	--	---	--	---	1	3,875	--	---	--	---	--	---	--	---	1	9,533	2	21,070	4	34,478
1914	3	2,949	6	7,735	1	2,225	2	6,366	1	5,169	--	---	1	7,375	--	---	--	---	3	34,510	17	66,339
1915 (June)	--	---	--	---	--	---	1	4,000	--	---	--	---	3	22,006	--	---	--	---	--	---	[illegible]	[illegible]
Total:	31	25,181	40	55,840	16	38,685	12	41,301	3	15,775	14	88,021	5	36,844	6	51,078	2	18,820	8	95,837	137	467,382

T A B L E II.

SHOWING THE NUMBER AND GROSS TONNAGE OF VESSELS BUILT IN EACH SHIPYARD UNDER THE SHIPBUILDING ENCOURAGEMENT ACT, YEARS 1897 - 1915.

Gross Tonnage. . Name of Shipyard	700-1000		1000-2000		2000-3000		3000-4000		5000-6000		6000-7000		7000-8000		8000-9000		9000-10,000		Above 10,000		Total	
	No.	G.T.	No.	G. T.	No.	G. T.	No.	G. T.	No.	G. T.	No.	G. T.	No.	G. T.	No.	G. T.	No.	G. T.	No.	G. T.	No.	G. T.
Mitsu-Bishi Dockyard and Eng.Wks. Nagasaki - Kobe	1	712	14	21,269	7	16,877	2	6,476	2	10,606	10	62,911	3	22,225	4	34,078	2	18,820	6	73,466	51	267,439
Kawasaki Dockyard, Limited K o b e	5	3.744	10	12,793	7	17,507	7	24,459	1	5,169	4	25,110	2	14,620	2	17,000	--	----	2	22,371	40	142,773
O s a k a Iron Works, Ltd. O s a k a	22	18,056	12	16,042	1	2,076	3	10,366	--	---	--	---	--	---	--	---	--	---	--	---	38	46,540
U r a g a Dock Co., Ltd. U r a g a	--	---	2	2,653	1	2,225	--	---	--	---	--	---	--	---	--	---	--	---	---	---	3	4,878
O n o Shipyard O s a k a	1	792	--	---	--	---	--	---	--	---	--	---	--	---	--	---	--	---	--	---	1	792
Fujinagata Shipyard O s a k a	1	961	--	---	--	---	--	---	--	---	--	---	--	---	--	---	--	---	--	---	1	961
Ishikawajima Ship.& Eng. Co. T o k i o	1	916	1	1,600	--	---	--	---	--	---	--	---	--	---	--	---	--	---	--	---	2	2,516
Kuchiki Shipyard	--	---	1	1,483	--	---	--	---	--	---	--	---	--	---	--	---	--	---	--	----	1	1,483

Tables are to end of June, 1915.

tion. In the Mitsubishi Dockyard, Nagasaki, the second-class cruiser "Yahagi", ocean-going destroyer "Yamakaze", despatch boat "Mogami"—all complete with their turbine machinery—beside several destroyers and torpedo boats, were thus built; while in the Kawasaki Dockyard, Kobe, the second-class cruiser "Hirato", despatch boat "Yodo" and several destroyers and torpedo boats were also built. By these firms, the powerful battle cruisers "Kirishima" and "Haruna" of 27,500 tons and 27 knots speed, similar to the "Kongo" built at Vickers' yard, England, and the "Hiyei", built at Yokosuka Dockyard, were completed early this year, having passed through steam and gunnery trials in a highly satisfactory manner. The large and powerful battle-ship "Fuso" of 30,600 tons, carrying 12-14-in. guns, (35.56 cm.) of purely Japanese design, was floated out of the new building dock at Kure Navy Yard last year; her three sisters are now under construction, one each at Yokosuka Navy Yard, Mitsubishi Works, Nagasaki, and Kawasaki Dockyard, Kobe, respectively. All structural materials including mild steel, high tension and nickel steel used in their constructions are supplied at home. After the outbreak of the present war, a supplementary budget was passed for the construction of 10 destroyers of 650 tons and 9500 i.h.p., to be completed in six months. These were built partly in navy and partly in private yards, and were all completed in the contract time and proved successful; home-made materials only are used in the construction of their hull, machinery and equipment.

Thus in the 12 years during and following the Russian War, viz: 1903-1915, only 7 ships of 62,000 tons, out of 78 vessels of 364,400 tons added to the Japanese Navy, have been ordered abroad; the rest have been supplied by the Government as well as private ship-yards at home, the share of the latter being about 40% in number and 26% in displacement. These facts are interesting, as showing the rapid growth of naval construction in Japan during the last decade and more.

PART II. TECHNICAL DEVELOPMENT.

Not only has Japanese ship-building advanced rapidly of late years, but the sizes of home-made vessels, both naval and mercantile, have also increased. This can be clearly seen from

the accompanying table (Table III) and diagrams (Plates II and III).

Merchant ships built under the Subsidy Act comprise varieties of type, but most of them are for carrying passengers and cargo, the largest being the "Tenyo Maru" and her two sisters. (See Tables IV and V.) New methods of weight-saving construction have been tried; wide frame spacing, omission of side stringers, skeleton floors, joggled framing, etc., have been adopted in a good many instances. Isherwood ships are now coming fast into favour in Japan, the "Peking Maru" and "Nanking Maru" of 3100 tons built for the Osaka Shosen Kaisha, in 1914, have proved very successful, and 16 more of the same type are now under construction at the Osaka Iron Works for several different owners.

In naval construction, every class of war-ships, from the heaviest battle-ship down to the shallow-draught river gunboat, has been built at home (see Table III); the navy yards at Yokosuka and Kure have turned out larger types, while these at Sasebo and Maizuru have supplied small criusers and destroyers only.

TABLE III.

SHOWING NUMBER AND DISPLACEMENT OF WARSHIPS LAUNCHED EACH YEAR

Year	Battleship		Battle Cruiser Armoured Cruiser		Cruiser		Despatch Boat and Gun Boat		Torpedo Boat and Destroyer	
	No.	Dispt.	No.	Dispt.	No.	Dispt.	No.	Dispt.	No.	Dispt.
1891	--	--	--	--	1	4,278	1	630	--	--
1892	--	--	--	--	1	3,126	--	--	--	--
1893	--	--	--	--	--	--	--	--	--	--
1894	--	--	--	--	--	--	--	--	--	--
1895	--	--	--	--	1	2,657	--	--	--	--
1896	--	--	--	--	--	--	1	1,772	--	--
1897	--	--	--	--	1	2,756	--	--	--	--
1898	--	--	--	--	--	--	--	--	--	--
1899	--	--	--	--	--	--	--	--	--	--
1900	--	--	--	--	--	--	1	1,238	6	321
1901	--	--	--	--	--	--	--	--	3	162
1902	--	--	--	--	2	6,732	--	--	5	981
1903	--	--	--	--	1	3,000	1	620	17	2,589
1904	--	--	--	--	--	--	--	--	4	831
1905	--	--	1	13,750	--	--	--	--	12	4,500
1906	1	19,200	1	13,750	--	--	--	--	18	6,750
1907	1	19,800	2	29,200	1	4,100	1	1,250	2	750
1908	--	--	--	--	--	--	1	1,350	1	375
1909	--	--	--	--	--	--	--	--	1	375
1910	1	20,800	--	--	--	--	--	--	1	1,150
1911	1	20,800	--	--	3	14,850	1	250	3	2.360
1912	--	--	1	27,500	--	--	1	785	2	--
1913	--	--	2	55,000	--	--	--	--	--	--
1914	1	30,600	--	--	--	--	--	--	--	--
1915	--	--	--	--	--	--	--	--	10	6,650

DIAGRAM SHOWING THE LARGEST WAR SHIP LAUNCHED EACH YEAR.

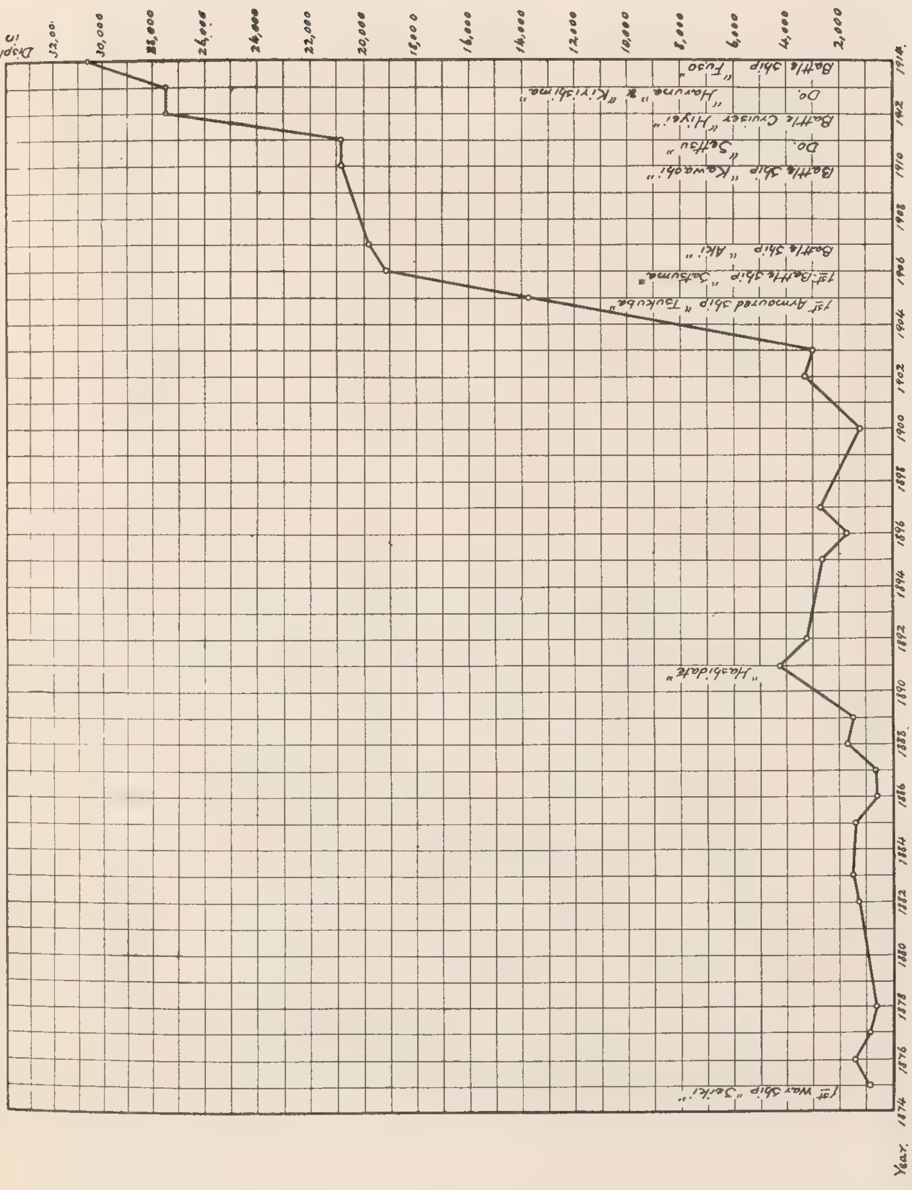

Plate II.

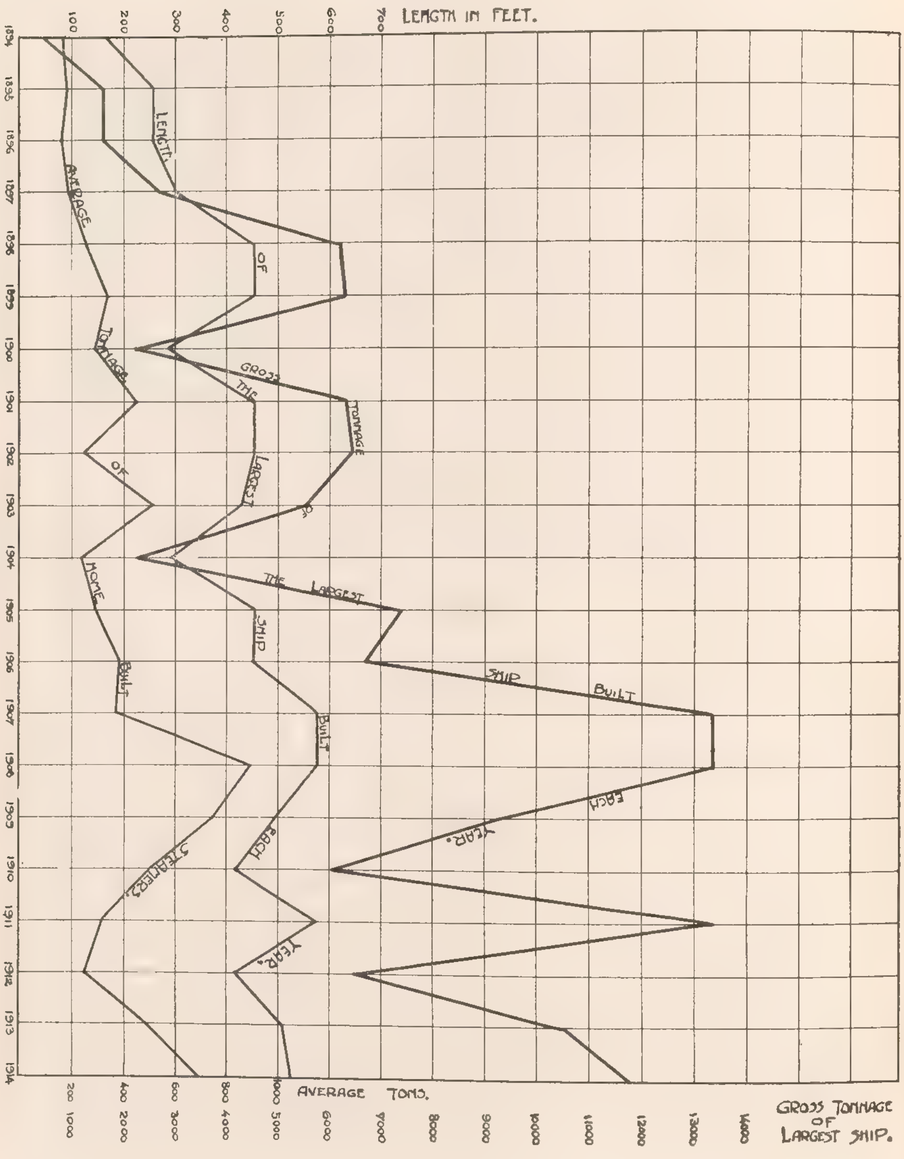

Plate III.

T A B L E I V.

SHOWING THE TYPE OF VESSELS BUILT UNDER THE SHIPBUILDING ENCOURAGEMENT LAW, YEARS 1897 - 1915

Type	Full scantling vessel		Spar decked vessel		Awning decked vessel		Shelter decked vessel		Shallow draught steamer		Total	
Year	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage	No.	Gross Tonnage
1897	--	--	--	--	1	727	--	--	--	--	1	727
1898	2	7,691	--	--	--	--	--	--	--	--	2	7,691
1899	2	8,026	--	--	--	--	--	--	1	1,694	3	9,720
1900	--	--	2	3,144	--	--	--	--	2	4,489	4	7,633
1901	3	13,332	1	1,600	3	2,950	--	--	2	4,787	9	22,669
1902	5	13,943	1	1,933	1	1,075	--	--	----	--	7	16,951
1903	4	15,076	3	3,912	--	--	--	--	2	1,870	9	20,858
1904	3	10,548	6	5,120	--	--	--	--	--	--	9	15,668
1905	--	--	5	7,053	3	4,617	--	--	1	1,759	9	13,429
1906	1	6,715	7	7,052	3	3,981	--	--	2	5,046	13	22,794
1907	1	8,523	8	10,789	--	--	2	26,880	2	7,176	13	53,368
1908	4	34,043	4	6,675	--	--	1	3,204	--	--	8	40,718
1909	4	27,054	2	1,785	--	--	2	12,559	--	--	8	41,398
1910	3	15,060	1	757	--	--	--	--	--	--	4	15,817
1911	2	7,323	3	3,235	--	--	1	13,377	--	--	6	23,935
1912	3	7,932	--	--	4	19,251	--	--	--	--	7	27,183
1913	2	21,070	--	--	2	13,408	--	--	--	--	4	34,478
1914	14	59,182	2	1,988	1	5,169	--	--	--	--	17	66,339
1915 (June)	3	22,006	--	----	--	--	--	--	1	4,000	4	26,006
Total	56		44	51,839	18	51,178	6	56,020	13	30,821	137	467,382

T A B L E V.

SHOWING THE TYPE OF VESSELS BUILT UNDER THE SHIPBUILDING ENCOURAGEMENT LAW, YEARS 1897 - 1915

Year	Ocean Going Passenger Ship	Ocean Going Cargo and Passenger Ship	Ocean Going Freighter	Coasting Cargo and Passenger Ship	Coasting Freighter	River Steamer	Channel Steamer	Vessels for Special Service
1897	--	--	--	-1 - 727	--	--	--	--
1898	--	1 - 6,172	--	--	--	1 - 1,694	--	Training Sailing Ship 1 - 1,519
1899	--	1 - 6,309	--	--	1 - 1,717	--	--	--
1900	--	--	--	1 - 1,576	--	2 - 4,489	--	--
1901	--	2 - 12,620	--	5 - 6,118	--	2 - 4,787	--	Salvage Steamer 1 - 712
1902	--	1 - 6,443	--	3 - 4,215	2 - 5,569	--	--	Lighthouse Tender 1 - 724
1903	1 - 5,538	--	1 - 5,068	3 - 3,912	1 - 2,183	2 - 1,870	--	--
1904	--	--	--	4 - 3,562	1 - 2,029	--	--	Training Sailing Ship 1 - 2,287 1 - 1,057 Lighthouse Tender
1905	--	1 - 7,463	--	9 - 11,204	--	1 - 1,759	2 - 3,359	--
1906	--	1 - 6,715	--	8 - 8,243	--	2 - 5,046	--	Cable Steamer 1 - 1,455
1907	1 - 13,454	--	--	8 - 10,789	--	2 - 7,176	--	--
1908	7 - 59,196	--	--	3 - 3,471	--	--	--	--
1909	2 - 11,784	3 - 18,542	1 - 9,287 Oil Tanker.	2 - 1,785	--	--	--	--
1910	--	2 - 12,120	--	1 - 757	1 - 2,940	--	--	--
1911	1 - 13,377	1 - 6,063	--	3 - 3,235	--	--	--	Dredger 1 - 1,260
1912	--	2 - 13,057	--	1 - 3,606	1 - 2,933	--	2 - 6,214	Dredger 1 - 1,393
1913	3 - 24,945	1 - 9,533	--	1 - 1,193	--	--	--	--
1914	4 - 39,679	--	3 - 13,741	5 - 4,997	4 - 6,729	--	--	--
1915 (June)	--	--	3 - 22,006	--	--	1 - 4,000	--	--
Total:	19 -167,973	16 -105,017	8 - 50,102	58 .- 69,390	11 - 24,100	13 - 30,821	4 - 9,573	8 - 10,406

GRAND TOTAL: 137 - 467,382.

Of the private yards, The Mitsubishi Works at Nagasaki and the Kawasaki Dockyard Co., Kobe, have been entrusted with the construction of the heavier war-ships, and the Osaka Iron Works and Uraga Dock Co. have constructed a few destroyers.

The use of high tensile steel in war-ship construction has been subjected to very careful study and exhaustive tests in one of the navy yards; and the parts of the structures subjected to severe longitudinal stresses in recent battle-ships, cruisers and destroyers have been made of this kind of special steel, all supplied from the Government Steel Works at Wakamatsu.

All the principal ship-building works in Japan, both navy and private, have lately extended their facilities for construction at a rapid rate. The scarcity of skilled labour, the increase in dimensions of ships built, with corresponding increase in the size of items of structure, the lack of physique of the men where a large amount of manual labour is required, and the consideration of economy coupled with rapidity of production and good quality of work, have necessitated improvements in general appliances of ship-yards, more especially the lifting and transporting equipment. Among conspicuous matters of this sort may be mentioned overhead lifting appliances now installed on building slips of all the principal yards; a large building dock with overhead cranes —length on bottom floor 698′ (212.8 m.), breadth of entrance 108′ (32.9 m.) on water level and 103′ (31.4 m.) on sill, and depth of water on sill 23′-3″ (7.1 m.)—lately constructed at the Kure Navy Yard, with the object of minimizing the risk accompanying the launching of heavy ships; the battle-ship "Fuso" of 30,600 tons was built in this dock. Some instances of the great saving in labour through the use of the transporting equipments may be cited. Comparing the labour spent, up to the time of launching, in the armoured cruisers "Tsukuba" and "Ikoma" built at Kure before, and the "Ibuki" and "Settsu" built after the installation of the gantry crane, the number of men employed per ton of material was reduced by about 60%; while in the case of the battle cruiser "Hiyei" and battle-ship "Kawachi" built in Yokosuka under gantry crane, a similar saving in the labour bill is shown when compared with the "Satsuma" and "Kurama" built with ordinary derricks.

The want of iron and steel material has been the greatest

drawback to the development of Japanese ship-building; and to remedy this defect, the Government started large steel works at Wakamatsu, near Moji, in 1898. Iron ores are imported mostly from China and Corea; the works can now produce, in a year, a little over 200,000 tons of structural steel of different descriptions, including plates, bars, rods, etc., and should be able to supply about 350,000 tons in the near future when the present extension scheme is completed. This provides, however, only for a minor part of the structural steel required by the country; as the Government gets the first call, the shortage takes effect chiefly in the case of mercantile needs, and to meet these demands supplies must be ordered from abroad. Out of 137 vessels built under the Subsidy Act, only about a dozen vessels have been built with home-made steel. Steel materials for merchant ships now under construction amount to about 110,000 tons, of which only 27,000 tons are to be supplied at home. (May, 1915.)

The plant for the manufacture of armour plates was first started in 1902 at the Kure Navy Yard, where armour plates for home-built ships have been and are being supplied. The quality is fully up to the best armour plate of the day.

For the supply of steel castings, works are ever increasing in both number and importance. The steel foundry at the Kure Navy Yard is of special value, where the largest castings and forgings, beside those required for armour plates and ordnance, are turned out. The Muroran steel works, primarily intended for supply of guns, are also in the market for shafts and other large forgings, and all kinds of steel castings, large and small. In addition to these, the Sumitomo steel works at Osaka, the steel foundry at Kawasaki Dockyard, Kobe, and the Kobe steel works, can all furnish castings of moderate size. All ordinary requirements are thus met within the country.

Anchors and chain cables are made at a few works in Osaka and Kobe, but iron bars for manufacturing cable are imported. Ropes, both hemp and steel, are now all made in the country; steel wires being supplied partly at home and partly from Europe. Boiler and condenser tubes have begun to be rolled lately at the Sumitomo Works in Osaka. Deck and other auxiliary machinery is mostly made in the country; so also are small ship fittings.

PART III. PACIFIC LINERS.

As an illustration showing the advance of Japanese ship-building, a brief account of the development of passenger and freight steamers used on the Trans-Pacific service may be cited.

The Japanese passenger service with San Francisco was first established in 1898, under Government subvention, by the Toyo Kisen Kaisha, with 3 twin-screw steamers of 6180 tons gross and 17 knots speed—the "Nippon Maru", "Hongkong Maru" and "America Maru"—built specially for the purpose in England. These steamers have accommodation for 100 first-class, 20 intermediate and 500 steerage passengers, and cargo-carrying capacity of 4500 tons. They were the best equipped passenger ships on the Pacific Ocean at that time, and the line soon became very popular among the traveling public. It was not long before the company again felt the necessity of improving its fleet by the addition of high-class passenger vessels, larger and faster than any liners then running on similar service. This was met by the construction of the "Tenyo Maru", "Chiyo Maru" and "Shinyo Maru", all built at the Mitsubishi Works at Nagasaki; the first two of them were launched in 1907 and put on the service in the following year, while the third was completed in 1911. They are not only the largest yet produced in the Orient, and the first turbine steamers in Pacific waters, but they also present many noteworthy features in both design and appointment.

The principal dimensions are:

Length between perpendiculars	550 ft. 0 in. (167.64 m.)
Breadth moulded	63 ft. 0 in. (19.202 m.)
Depth moulded to upper deck	38 ft. 6 in. (11.734 m.)
Depth moulded to shelter deck	46 ft. 6 in. (14.173 m.)
Load draught (to Lloyd's Summer Freeboard)	31 ft. 8 in. (9.654 m.)
Load displacement	21,660 tons
Dead weight	10,330 tons
Cargo capacity at 40 c. f. (1.133 cu. m.) per ton	8,700 tons
Gross tonnage	13,398 tons

They are of the complete shelter-deck type, built to Lloyd's highest requirements. The number of passengers carried in case of the "Tenyo Maru" is: 260 first class; 47 second class

and 816 third class. In general finish and fittings, they were quite equal to the highest-class Atlantic liners then afloat; no pains were spared in order to supply every possible comfort and luxury to the travelers. These vessels are driven by Parsons' steam turbines with 3 propellers, and have 13 single-ended boilers, 15 ft. 9 in. (4.802 m.) diameter, burning fuel oil. The mean speed attained on trial, at the draught of 24 ft. 9 in. (7.545 m.) was 20.5 knots (Chiyo Maru) with shaft horsepower of about 20,000. In ordinary sea condition they can easily maintain mean speed of 18½ knots with twelve boilers.

They really represented the highest development of ship-building and engineering work at the time. It is true that steam turbine machinery had at this time been fitted on a number of steamers in Europe, but these latter were of comparatively small displacement; the larger ships with turbines (the "Virginian" and "Carmania" for instance) were not then in service. The merits of oil fuel as against coal were also quite well known, but probably on account of its limited supply, oil fuel had not come into general use; the only vessels burning oil as fuel were oil tankers and small coasting vessels navigating in the oil districts. No one can help admiring the foresight, enterprise and courage which characterized the decision of the Toyo Kisen Kaisha in adopting these novelties in the three Pacific liners; the decision has since proved to be fully justified by the results obtained in actual service.

Oil is carried in a part of the double bottom tanks and in two deep tanks, with total capacity for oil storage of 3625 tons, a quantity sufficient to run the vessel for about 27 steaming days at an average service speed of 15 knots, covering a distance of about 10,000 miles; the deficit for a round trip had to be supplied in China or Japan. The actual rate of consumption of oil on service, compared with that of coal observed on the consumption trials made by the builders, is approximately in the ratio of 2 to 3.

However, owing to the uncertainty of supply of oil fuel in Japan and China, the owners decided, in 1911, to burn coal at this end of the voyage. The forward battery of boilers (six in number) was therefore converted to use coal as fuel, while

the after battery, consisting of 7 boilers was still to burn oil. As 10 boilers are commonly needed in ordinary service, the coal and oil-burning boilers are used in combination to suit local conditions of fuel supply, the consumption in the case of coal burning being 20 to 22 tons against 14 tons of fuel oil. In order to obtain further economy in fuel consumption, a new scheme of mixed firing, by spraying oil fuel over burning coal, is now being tried in one of these steamers. On the other hand, the "Shinyo Maru" is at present using coal alone.

The decorative work of these vessels presents quite an unique feature. It is entirely of Oriental design by an expert architect, based upon typical styles of Japanese fine arts of different periods, with rich and luxurious display of beautiful silk fabrics, used as panels, door curtains and upholstery. The result is a very successful attempt to adapt Japanese art to European, in meeting the exceedingly strict requirements of this portion of the ship's finish, in which taste and utility each form an important and exacting part.

The Toyo Kisen Kaisha had also established in 1908 a freight service with the West Coast of South America; the subsidy has been granted on the line since 1909. Three cargo vessels, ranging from 6000 to 9000 tons gross, with accommodation for a few cabin passengers and emigrants are used for the service. The latest addition to this fleet is the "Anyo Maru" of 9256 tons, built at the Mitsubishi Works, Nagasaki, in 1913. She was the largest steamer fitted with Parsons' geared turbines at that time. Her particulars are as follows:

Type	Shelter Deck
Length between perpendiculars	460 ft. 0 in. (140.24 m.)
Breadth moulded	60 ft. 0 in. (18.288 m.)
Depth moulded	32 ft. 6 in. Up. Dk. (9.906 m.)
Load draught	30 ft. 4 in. (9.247 m.)
Dead weight	12,540 tons
Cargo capacity	11,110 tons
Speed in knots	15.3
S.H.P.	7,500

No. of passengers—30 1st-class, 50 2nd-class, 640 emigrants.

The regular freight service with Seattle, under the Japanese flag, was commenced in 1896, by the Nippon Yusen Kaisha,

the largest shipping company in Japan, with 3 second-hand cargo steamers ranging from 3000 to 6000 tons in gross tonnage. The steamers connected with the Great Northern Railway Co. of the United States. Subsidy has been granted on this line since 1900, and three new vessels of 6300 tons and 15 knots speed were built, in 1901, specially for the service; the "Shinano Maru" in Glasgow, and the "Kaga Maru" and "Iyo Maru" at the Mitsubishi Works, Nagasaki. These steamers are of the semi-passenger type, with accommodations for 36 first class and 400 steerage passengers. Three more vessels were afterwards added to the line, owing to the development of the trade; the "Aki Maru", a sister ship to "Kaga Maru", in 1903, and the "Tango Maru", of 7463 tons, in 1906—both built for the service at the Mitsubishi Works, Nagasaki. With these six steamers the company began to keep up a fortnightly service from both termini.

After the revision of the Government Subsidy Act in 1909, some changes took place in the company's fleet distribution. The "Tango Maru" and three others were withdrawn from this service and replaced by ships of similar size but older build, two of which were again replaced in 1912 by the "Yokohama Maru" and "Shizuoka Maru", specially designed for the line. On account of the high seas prevailing during the winter months in the Northern Pacific, many steamers of the ordinary three-island type, used on this route, had shown weakness in way of the breaks of the bridge deck; then again the cargoes carried on this line are generally of a lighter nature, and larger 'tween-deck spaces are needed. These facts resulted in the adoption of the shelter-deck type for the "Yokohama Maru" and "Shizuoka Maru", the latest addition to the service. The principal particulars of three different types built for the Seattle line are as on the following page.

There has been some talk of the Nippon Yusen Kaisha establishing a new line of freight steamers to the east coast of the United States, via Panama Canal, as an extension of the present Seattle line; a similar scheme has been proposed by the Toyo Kisen Kaisha, which now runs a regular service to Central and South America. It is very hard to predict at

		Kaga Maru	Tango Maru	Yokohama Maru
Type		3 deck with P.B.F.	3 deck with P.B.F.	Shelter deck
Length B.P.		445′ 0″ (135.67 m.)	445′ 0″ (135.67 m.)	400′ 0″ (121.95 m.)
Breadth mld.		49′ 0″ (14.935 m.)	52′ 0″ (15.850 m.)	50′ 0″ (15.240 m.)
Depth mld.		33′ 0″ (10.058 m.)	33′ 6″ (10.210 m.)	30′ 0″ (up dk) (9.144 m.) 38′ 0″ (sh dk) (11.582 m.)
Max. draught		25′ 9″ (7.85 m.)	26′ 0″ (7.925 m.)	27′ 0″ (8.230 m.)
Dead weight		7300	7920	7870
Cargo capacity		7340	8100	8058
Max. speed on trial		15.28	15.60	15.17
I.H.P.		5600	6430	5620
Gross tonnage		6300	7463	6147
No. of passengers—	1st-class	36	60	28
	2nd-class	12	26	-------
	3rd-class	474	362	204

Where built—Kaga Maru, Tango Maru and Yokohama Maru, Mitsubishi Works, Nagasaki; Shizuoka Maru, Kawasaki, Kobe.

present which company will be ultimately favoured with the Government support. The former company, however, commenced a few months ago an irregular cargo service to Europe via Suez Canal, without receiving any subsidy, with 6 new cargo steamers of 7300 tons gross, of which the "Toyooka", "Toyama", "Toyohashi" and "Tokuyama Maru" were built at home, being just completed, and the "Tsushima" and "Takata Maru" in Scotland. Some of these steamers are making the "round-the-world" trip, calling at the east coast of the United States and coming home by way of Panama Canal. The particulars of these ships are given on the following page.

They have a few spare cabins but no steerage accommodation, and are provided with most modern appliances for working cargo.

Of these six steamers, those built at the Mitsubishi Works—the "Toyo-oka" and Toyama Maru"—are fitted with Parsons'

	Toyooka Maru	Toyohashi Maru	Tsushima Maru
Length B.P.	445′ 0″ (135.67 m.)	445′ 0″ (135.67 m.)	445′ 0″ (135.67 m.)
Breadth moulded	58′ 0″ (17.678 m.)	58′ 0″	58′ 0″
Depth moulded	34′ 0″ (10.363 m.)	34′ 0″	34′ 0″
Load draught	26′ 7½″ (8.117 m.)	26′ 5.8″ (8.074 m.)	26′ 10½″ (8.193 m.)
Dead weight	10,870 tons	10,650 tons	10,450 tons
Cargo capacity	12,564 tons	12,123 tons	11,925 tons
Gross tonnage	7,378 tons	7,298 tons	6,723 tons
Speed in knots	14.5	14.55	13.7
I.H.P.	5,330 S.H.P.	5,995	4,396

Where built—Toyooka Maru, Mitsubishi Works, Nagasaki; Toyohashi Maru, Kawasaki Dockyard, Kobe; Tsushima Maru, Russel, Glasgow.

geared turbines, driving twin screws; and those from the Kawasaki Dockyard,—the "Toyohashi" and "Tokuyama Maru"—have boilers fitted with superheaters; while the other two, built in Scotland, have reciprocating engines and ordinary Scotch boilers. The relative economy in their coal consumptions is now being watched with great interest.

The Osaka Shosen Kaisha entered into a contract, in 1907, with the Chicago, Milwaukee and Puget Sound Railway Company for the joint freight service between Tacoma and Hongkong, via Japanese ports. The line commenced running in 1909 with six new cargo steamers of 6000 tons gross, receiving subsidy from the Government. These steamers were all built at home, the "Tacoma", "Seattle" and "Chicago Maru" at the Kawasaki Dockyard, Kobe, and the "Panama", "Mexico" and "Canada Maru" at the Mitsubishi Works, Nagasaki; their particulars are as on the following page.

They are pure cargo ships with three spare cabins and accommodation for about 200 emigrants. The line has been very successful, and two new ships of about 9500 tons gross—475′ x 61′ x 40′ 9″ (144.82 m. x 18.593 m. x 12.424 m.) to shelter deck; deadweight about 12,000 tons on 28′ 0″ (8.534 m.)—are now being built for that service, the "Manila Maru" at the Mitsubishi Works, Nagasaki, and the "Hawaii Maru" at

	Tacoma Maru	Panama Maru
Length B.P.	400′ 0″ (121.95 m.)	400′ 0″ (121.95 m.)
Breadth moulded	51′ 3″ (15.625 m.)	51′ 0″ (15.545 m.)
Depth moulded	32′ 6″ (9.906 m.)	32′ 6″ (9.906 m.)
Load draught	25′ 5½″ (7.761 m.)	26′ 0″ (7.925 m.)
Dead weight	7676 tons	7680 tons
Cargo capacity	8400 tons	8170 tons
Gross tonnage	5841 tons	5790 tons
Speed	15.4 knots	15 knots
I.H.P.	4800	5226

Where built—Tacoma Maru, Kawasaki Dockyard; Panama Maru, Mitsubishi Works.

the Kawasaki Works, Kobe. They were launched sometime ago, and will be ready for the service before long. (June 1915.)

Under the new convention just passed at a special sitting of the Diet, the subsidized routes to Seattle and Tacoma are merged into one, called "Puget Sound Line", for which subsity is granted only to six steamers, two of the Nippon Yusen Kaisha and four of the Osaka Shosen Kaisha. Both companies, however, are running six steamers each, keeping up a fortnightly service regularly as before.

DISCUSSION

Admiral Kondo.

Admiral M. Kondo,† in reply to a question from Mr. H. P. Frear as to what factors other than high cost of materials rendered ship construction more expensive in Japan than in America or Europe, stated that Japanese workmen were physically not well suited to ordinary ship construction. He said that they were particularly successful in building small and high-speed boats, such as torpedo boat destroyers, but for merchant work, the low daily pay did not compensate for lack of efficiency. There might be other factors with which he was unacquainted at the time.

† Ministry of Marine, Tokyo, Japan.

Paper No. 199

BULK FREIGHT VESSELS OF THE GREAT LAKES.

By

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The transportation of bulk freight upon the Great Lakes of North America, involves several problems which are unique to this region, and which differ materially from those which obtain for vessels in similar service on the high seas. A short discussion of the above may not be amiss, as the development of the "Lake Freighter" has been governed almost exclusively by them.

CARGOES AND HANDLING.

The three main staples are iron ore, grain and coal; the former being shipped eastward, from the ports on Lake Superior, to Chicago and the Lake Erie ports; and the last, between the same places, but in the opposite direction. The various amounts of these commodities shipped during the past ten years are shown in Fig. 1; the iron ore being in gross (2240 lbs.), and the wheat and coal, in net tons (2000 lbs.). Although there have been minor fluctuations, the general tendency has been upwards, until under normal conditions today, the total amounts to nearly 100,000,000 tons, about one half of which is iron ore. Owing to the frozen condition of the Lakes during the winter, the above amount must be carried during a period of about six months. This condition has led to two important considerations so far as the vessels are concerned, viz: a gradual increase in size, and the need of utmost dispatch in loading and unloading, so that the time in port may be reduced to a minimum. During the past ten years the size of vessels has increased from about 440 feet long (134 m.) and 6500 tons capacity, to 600 feet long (183 m.) and 12,000 tons capacity, and in a few cases slightly larger.

The loading and unloading facilities have, perhaps, had more effect upon the structural design of the vessels than the amount carried. As is generally known, the vessels themselves

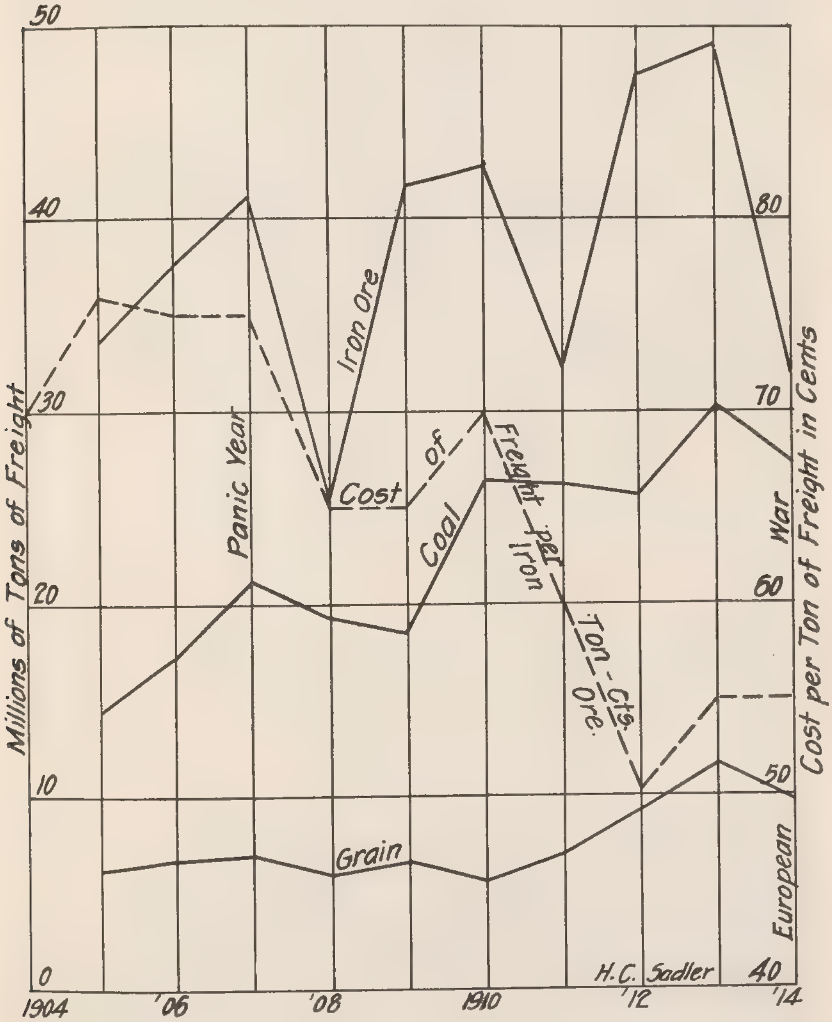


FIG. I ANNUAL TONNAGES

carry no appliances of any sort for handling cargoes; this being done entirely from the shore. In the early days, the hand-filled bucket, operated by a steam winch from the shore, was the standard. Later came the grab-bucket, mechanically op-

erated by means of wire ropes. This type, known as the Brown Hoist, but increased in size, is still largely used. Finally, there is the Hulett type, which is designed with rigid arms. For loading purposes the docks are so arranged that the ore or coal is carried in elevated bins, to which shoots are attached, which can be lowered to the hatches of the vessels. A standard spacing of twelve feet (3.66 m.) between the shoots has been adopted, and therefore the hatches of the vessels are placed either twelve or twenty-four feet apart.

Some figures as to the time taken to load a vessel with iron ore, in this manner, may be of interest. The record time, in 1911, was 9362 tons in twenty-five minutes, but this was under exceptional circumstances. A rate of about 5000 tons per hour is, however, not unusual. The average stay in the loading port is from ten to twelve hours, including everything.

So far as unloading is concerned, the record, established in 1912, was 10,636 tons in two hours and fifty minutes. Each machine of the modern Hulett type can, however, unload at an average of from 600 to 700 tons per hour, under favorable circumstances.

Illustrations of the installations of the different types of unloading machines and their methods of operation are shown in Figs. 2, 3, 4, 5 and 6, which also serve to show some general features of the vessels, and to which reference will be made later.

EFFECT OF ABOVE ON DESIGN.

These methods of loading and unloading have determined four principal features in the design of the vessels.

First, it is absolutely necessary to have the decks of the vessel clear from any encumbrances, such as houses, casings, etc., in order that the cargo operations may proceed with dispatch. This has led to the placing of the machinery as far aft, and the navigation part of the vessel, pilot house, etc., as far forward, as possible.

Second, the hatches must be placed to suit the spacing of the shoots at the loading docks, and must be as numerous as possible, to minimize the moving of the vessel or the unloading machines.

Fig. 2. One of four 15-ton Ore Unloading Machines on the dock of the Lake Shore & Michigan Southern Ry. at Ashtabula, Ohio.

Third, the depth of the vessel is governed somewhat by the height of the shoots, which must be at such an angle that the ore will flow from the bins.

Fig 3. Four 17½-ton Hulett Ore Unloading Machines and one 15-ton Ore Rehandling Bridge. Built for the Penn. Lines, Cleveland, Ohio.

Fig. 4. Brownhoist Ore Handling Equipment, Federal Furnace Co., South Chicago, Ill.

Fig. 5. Bucket of Hulett Ore Unloading Machine working in the hold of a Class "B" boat.

Fourth, the holds of the vessels should be as free as possible from any obstructions which would hamper the operations of the unloading machines.

OTHER FEATURES INFLUENCING DESIGN.

One of the principal limitations in the design of these vessels is the draught of water available. This has been fixed mainly at two points on the Lakes, viz: the depth available at the locks at the "Sault Sainte Marie", and at the "Lime Kiln Crossing" below Detroit. At present, the available depth is from 19′ 0″ to 20′ 0″ (5.8 to 6.0 m.), but with the new locks and improvements at the lower end of the Lakes, this will in the future be increased, probably to from 23′ 0″ to 25′ 0″ (7.0 to 7.6 m.).

The length and breadth have been somewhat limited by considerations of locks, channels, harbors, etc., and at present it would appear that, from an economical standpoint, there is not much to be gained by any further increase in size above about 600 feet. It is well known that, from an economical

standpoint, it does not pay to move heavy bulk cargoes at high rates of speed. The economical speed for the service on the Lakes appears to be about 11 to 11.5 miles per hour (10 knots); consequently the vessels are made of very full form, to get the maximum cargo capacity on the limited draught, and do not require a machinery installation of more than about 2000 i. h. p.

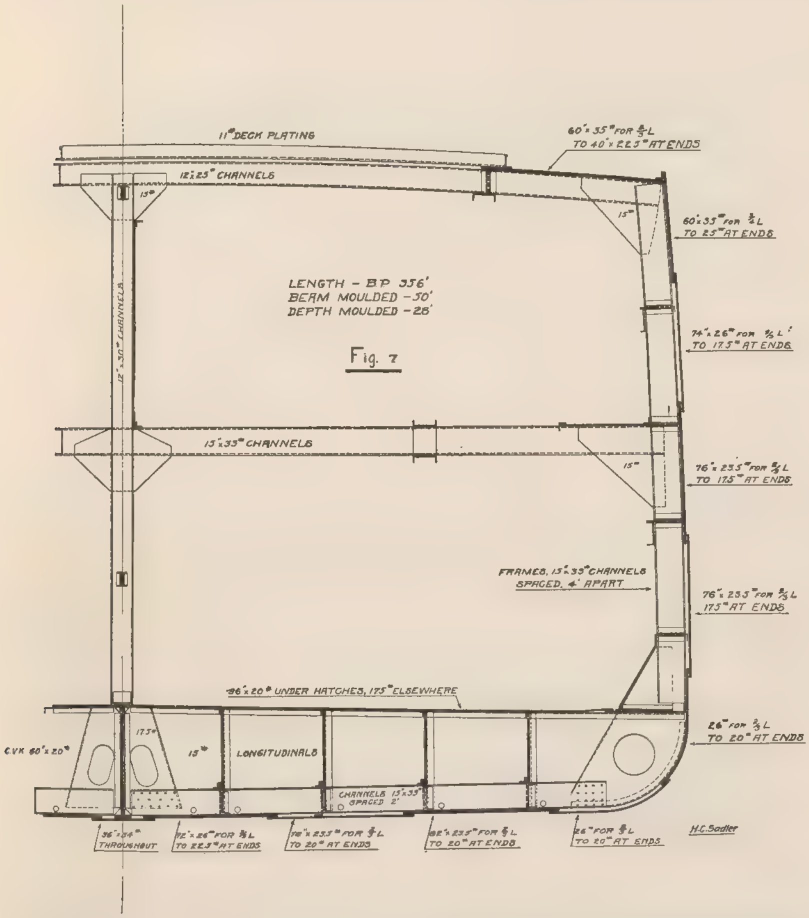
STRUCTURAL FEATURES.

The earlier types were single-decked vessels with hold beams and stanchions between the hatches, and fitted with the usual double bottom which was flush plated to facilitate unloading. Wide belt or web frames were also fitted between the hatches. A typical midship section showing the general details is given in Fig. 7. A similar construction is shown in Fig. 5, which illustrates in an interesting way why this type has been abandoned. An examination of the photograph will show the damage to which certain structural members have been exposed, owing to the unloading grabs.

The next development was the substitution of the "arch" construction for stanchions and hold beams, thus leaving the

Fig. 6. Buckets working in the hold of a modern lake freighter, showing manner of cleaning up.

holds practically clear, except for the belt frames at the arches, which were usually fitted between each hatch (Fig. 8). As the size of vessels increased, it appeared necessary to increase the water ballast capacity and this, combined with the desire to have no projections which would be liable to injury, led to



the adoption of the side tanks. This form is illustrated in the midship section shown in Fig. 9 and may be regarded as the general standard type of the modern "Freighter" of today, suitable for carrying iron ore, coal or grain. The two latter cargoes, owing to their lighter density, require a much larger cubical capacity for a given weight, than iron ore, and hence the necessity for keeping the side tanks somewhat narrow.

There are, however, certain vessels owned by steel companies, which carry nothing but iron ore; the return trip being made in the ballast condition. In this type it is advantageous to have the cargo somewhat more concentrated near the center of the vessel, from considerations of both unloading and sea-

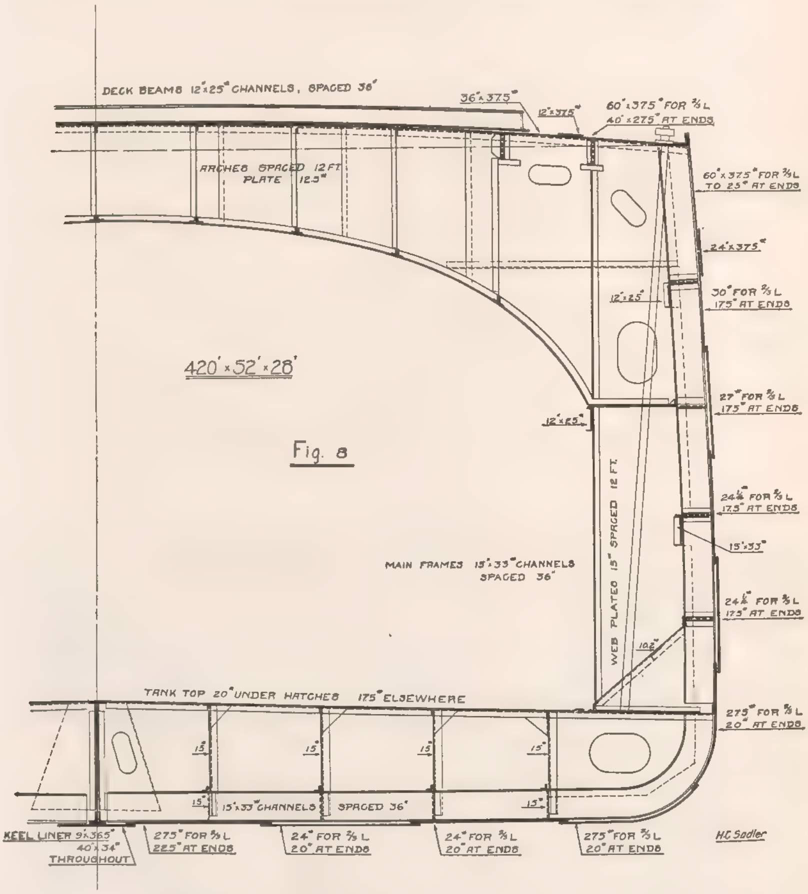


Fig. 8

going qualities. By somewhat restricting the breadth of hold, the center of gravity of the cargo is higher, and this helps to reduce the metacentric height, which is usually rather high in this type of vessel.

A midship section illustrating the principal features of this type of construction is shown in Fig. 10 and also in Fig. 6.

Fig. 10 also shows the arrangement for a vessel constructed

upon the longitudinal, or Isherwood, system. This type has not been very long in service on the Lakes, and although there was noticeable saving in weight in the earlier vessels, this has somewhat disappeared in the later ones, owing to the experience gained. It is, perhaps, beyond the scope of the present paper to enter into a minute discussion of the merits of the

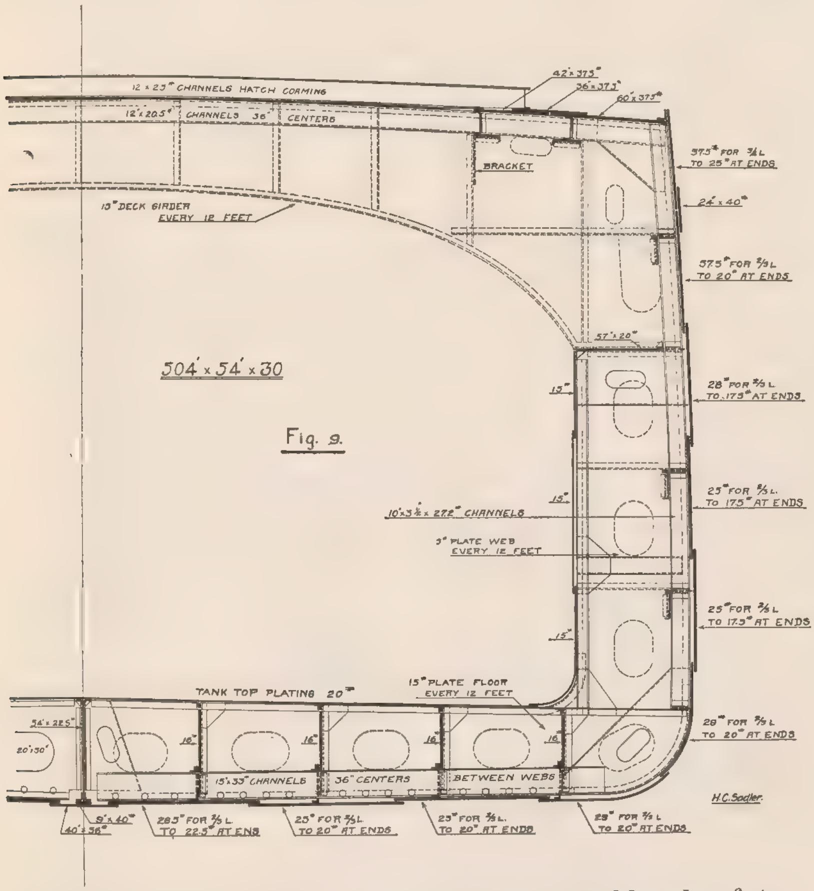
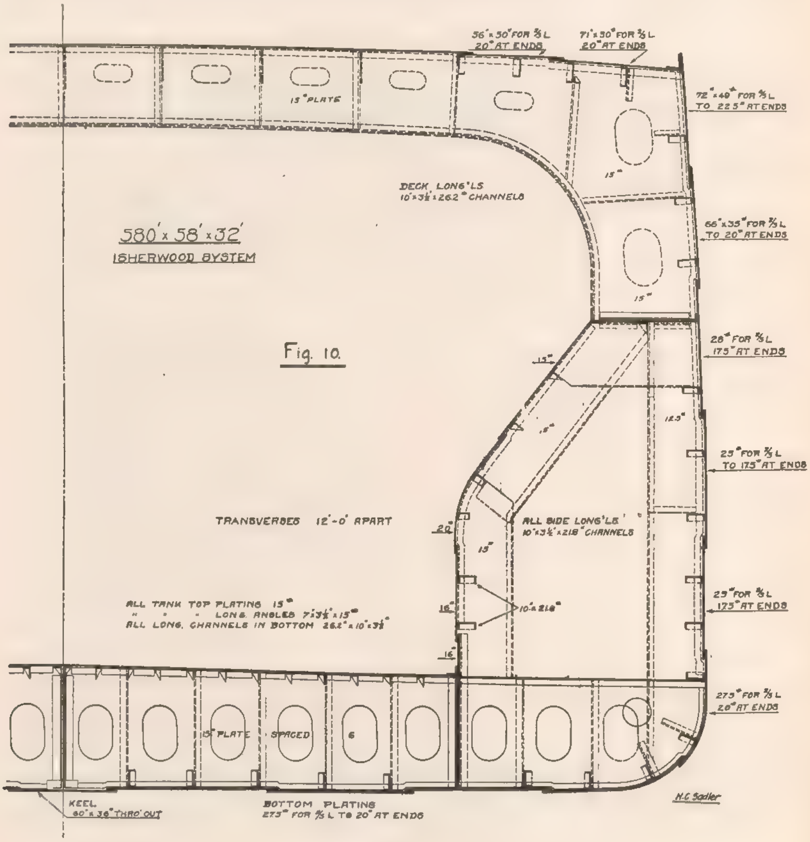


Fig. 9.

horizontal and transverse systems, but probably the future vessel will be somewhat of a compromise: longitudinally constructed in the bottom and decks, and transversely along the sides. There is certainly no doubt that the bilges of these vessels need good transverse strength, which is somewhat lacking in a purely longitudinal construction. During the great storm of 1913 a number of vessels were lost, not only of the "Lake"

but also of the "ocean-going" types. As thorough an investigation as possible was made, with the results that the deck houses aft are now made of more substantial construction, and fitted with heavy or storm doors and shutters; the hatch covers, when steel, have also been stiffened somewhat. Some companies, however, still prefer wood covers.



MACHINERY.

The machinery installation has become somewhat standardized, so far as the main engines and boilers are concerned.

The single-ended Scotch boiler with Howden system of forced draft or the induced draft is now almost universally used. The tendency of late has been to give the vessels a slightly larger boiler capacity, and in the boilers themselves, to shorten the length, so as to get the shell in one length of

plate and do away with the middle seam; otherwise the construction does not call for any particular comment. The "Sirocco" type of fan for the forced draft is gradually replacing the older type with vanes, and in some cases these are turbine driven. Full particulars of the boiler installation are given below.

The main engines are usually of the triple expansion, three-cylinder type, which, on the whole, appears to give the best satisfaction. Quadruple expansion engines are also used in some cases. The condenser is of the jet type, and the air pump is driven from the main engine. This pump is now either of the Davidson or double-acting type.

Some of the auxiliaries call for attention. Owing to the large amount of water ballast carried and the necessity of removing this rapidly when the vessel arrives at the loading docks, it is now customary to fit one or two large centrifugal pumps and one or two duplex plunger pumps for this purpose; the latter being used to take out the last few inches of water. The feed and sanitary pumps are either of the simplex or duplex type.

Full particulars of the engines, boilers and auxiliaries are given in the following tables, for a triple and quadruple expansion type:

	Triple.		Quadruple.
Cylinders	23½″, 38″, 63″		22¾″, 33¼″, 48″, 69″
Stroke	42″		42″
Boilers (2)	15′-4½″ x 12′-0″	(3)	14′-9″ x 12′-2½″
Pressure	180 lbs.		216 lbs.
Furnaces (6)	46″	(9)	44″
Grate Surface	126.5 sq. ft.		165 sq. ft.
Heating Surface	5998 sq. ft.		7788 sq. ft.
Connected Pumps, Air	27″ x 15″		30″ x 14″
Bilge	5″ x 12″		5″ x 12″
Cooler	3½″ x 12″		3½″ x 12″
Ballast (2)	12″ x 16″ x 18″	(2)	10″ x 14″ x 16″
Pumps (1)	12″ (cent.)	(2)	18″ (cent.)
Feed (1)	10″ x 6″ x 12″	(1)	14″ x 8½″ x 16″
Fire (1)	10″ x 6″ x 10″	(1)	12″ x 6″ x 12″
Deck (1)	8″ x 4″ x 10″	(1)	6″ x 4″ x 6″
Sanitary (1)	4½″ x 2¾″ x 4″	(1)	4½″ x 2¾″ x 4″
Electric outfit (2)	10 kw.	(2)	15 kw.

Trial Particulars.

Length O. A.	524 ft.	617 ft.
Beam	54 ft.	64 ft.
Depth	30 ft.	33 ft.
Draft mean	19 ft. 3 in.	16 ft. 10 in.
Dispt. (tons F. W.)	12,650	15,161
Speed (miles per hr.)	11.24	12.0
I. H. P.	1640	2212
Revs. per min.	82.13	81.5
Propeller dia.	14 ft. 8 in.	15 ft. 9 in.
" pitch	13 ft. 3 in.	13 ft. 9 in.
" surface	78.5 sq. ft.	91 sq. ft.

Although, in general, the machinery of these vessels has become more or less standardized, continued attention is being given to minor improvements, in order to increase its efficiency. Up to the present, the geared steam turbine, electric drive, and oil engine have not been tried, but serious consideration is being given to the first of these somewhat newer methods of propulsion.

In conclusion, the writer wishes to acknowledge his thanks to the American Shipbuilding Co. and the Great Lakes Engineering Works for kindly supplying certain data with regard to the vessels; and to the Wellman-Seaver Co. and the Brown Hoisting Machinery Co. for the illustrations of the unloading machinery.

Further and more detailed information relating to these vessels and their trade, may be found in the following:

Society Naval Architects & Marine Engineers, N. Y., Vols. 1, 4, 5, 13, 16, 17.

Institution of Naval Architects, Vol. 51.

The Marine Review, (Cleveland); numerous articles, plans, methods of construction, etc.

Annual Reports of the Lake Carriers' Association.

Reports of the U. S. Army Engineers; Lake surveys, locks, traffic statistics, etc.

DISCUSSION

Mr. Hugo P. Frear,‡ Mem. Soc. N. A. & M. E., wrote that although the lake ore carriers are successful on the Great Lakes, it is doubtful, on account of their proportions and excessive stability, if the same success would obtain on the ocean, where the seas are heavier and longer. The question of stability is always an important subject with ore carriers. Mr. Frear.

It is an impossibility to secure the most desirable stability in a vessel well adapted to carry both ore and coal or grain, if a full dead-weight cargo of each is to be provided for. If holds are sufficiently elevated and contracted to give the best results, so far as stability is concerned with an ore cargo, the cubic space for coal or grain would not be sufficient to carry the full dead-weight, and on this account the Lake designs are a compromise. The holds have only been contracted, as experience has been gained, sufficiently to obtain a stability that would be possible to operate with on the Great Lakes, taking the heaviest weather obtaining there into consideration, thereby providing all possible space for lighter bulk cargoes.

It is true that there are many ordinary tramp or cargo steamers carrying iron ore on the high seas with greater or less success. Nevertheless, while these vessels usually have better proportions of length to depth and breadth to draft, the repairs are excessive and occasionally one is reported as missing.

In the early days, iron and copper ore were carried on the ocean in wooden sailing vessels, and in order to reduce the stability sufficiently for sea-worthiness, the holds were blocked up several feet and contracted sideways by longitudinal wood wing bulkheads shored from the ships' sides. In some cases, wood and even empty barrels were stowed at the sides to contract the holds.

He stated that he had recently designed some ore carriers for the Bethlehem Steel Company to be used exclusively in carrying iron ore from Cruz Grande, Chile, to New York. These vessels were 500 ft. by 66 ft. by 42 ft. moulded depth. The double bottom was elevated 17 ft. above the keel and, by means of wing longitudinal bulkheads, the hold was contracted to one-half breadth or 33 ft. 0 in. The calculated metacentric height on a mean draft of about 31 ft., and with about 15,000 long tons of ore, was about 30 in.

‡ Naval Architect, Union Iron Works Co., San Francisco, Calif.

Paper No. 200

RIVER, LAKE, BAY AND SOUND STEAMERS OF THE UNITED STATES.

By

ANDREW FLETCHER, Mem. S. N. A. & M. E.
Hoboken, N. J., U. S. A.

The writer considered that this paper would be of more value to the members of the Engineering Congress if authentic drawings of the midship cross sections with scantlings, deck plans, elevations and a data sheet of general dimensions, draft, displacement, trial speed and motive power were furnished of a number of well-known and successful steamers of the United States, than if a detailed description and analysis of a steamer of each of the types included in the title of this paper were given.

The steamers selected are of the steamboat type, with the exceptions of the turbine steamers "Yale" and "Harvard", which, however, were built for Sound and short outside sea service; the steamer "Governor Cobb", the first Parsons marine-turbine steamer built in the United States; and the turbine steamer "Belfast". The plans of these turbine steamers have not been published by any of the engineering societies. The varied services they have been engaged in since they were built have shown their adaptability for general service, particularly in the cases of the "Yale" and "Harvard" and the "Governor Cobb".

Extreme shallow-draft and stern-wheel steamers are omitted and the members are referred to Transactions of the Society of Naval Architects and Marine Engineers, Vol. 17, 1909, which contains an interesting paper on the subject.

The general data sheet and plans were compiled from information obtained from the various builders and naval architects

of the steamers, who very courteously and freely gave the information.

The Hudson River steamers selected are:

The paddle steamer "Washington Irving", the largest, speediest, finest, and the latest addition to the world-wide known Albany Day Line, operating the finest fleet of day passenger steamers in the United States. This steamer is engaged in purely passenger service and has a Government license for 6000 passengers, has carried the maximum number many times without an accident, and is generally considered the best equipped of her type and size in river day-boat service.

The paddle steamer "Berkshire" of the Albany Night Line, Hudson Navigation Company, the largest and finest steamer engaged in Hudson River night passenger and express-freight service. It can justly be said that she is a first-class modern five-story floating hotel.

The single-screw steamer "Benjamin B. Odell", a combination freight and passenger steamer, built a few years since. It will be noted on her plans that the deck width is carried unusually far aft for increased accommodations, the quiet waters of the Hudson permitting the large overhang of the guards with comparatively low freeboard.

The Potomac River and Chesapeake Bay services are represented by the single-screw passenger and freight steamer "Northland" and the twin-screw steamer "Maryland". Both of these steamers have given excellent results.

The Great Lakes have had many large, well-equipped and very successful steamers of the steamboat type added to their fleet in recent years, the latest production being the "Seeandbee" of the Cleveland & Buffalo Line. This steamer is the largest paddle steamer in the world, has in the neighborhood of 500 rooms, and no expense was spared in her building to make her most complete, luxurious, comfortable and safe. The Marine Review, November, 1912, gives an excellent description of this steamer.

The inland lakes are here represented by the paddle steamer "Horicon", the largest steamboat of the Lake George (New York) Steamboat Company. This steamboat is of the excursion type. It is engaged on a route of approximately 30

miles, making sixteen dock landings from end to end of lake, with railroad connections at terminals. Due to recent exactions of New York State laws, no sewage, waste matter or unclean water is permitted to be discharged into the lake, and sewage tanks of sufficient capacity for a round trip of about 60 miles are fitted in this steamer. With a licensed capacity for 1600 passengers (very often carried), the retention and quick disposal of the sewage, etc., was an interesting study.

The Pacific Coast steamboats are represented by the single-screw steamer "Tacoma", the latest and largest of the Inland Navigation Company, of Seattle, Washington.

The paddle steamer "Rose Standish", of the harbor and bay excursion type, is the latest addition to the fleet of Nantasket Beach Steamboat Company, operating in Boston Harbor and connecting the shore towns of Massachusetts Bay with the city of Boston.

Long Island Sound steamers are represented by the paddle steamer "Priscilla" of the celebrated Fall River Line, New York to Boston, Mass., water and rail route. This steamer has been very successful in every way and is most completely equipped. Her machinery—of the double inclined compound type with two high-pressure cylinders forward of main paddle shafts and two low-pressure cylinders aft, two sets of main cranks, double-beat poppet valves with Sickle's dash-pot cut-off on the high-pressure cylinders, and double-beat poppet valves with Stevens fixed cut-off on the low-pressure cylinders, the valves being operated by Stephenson link gear—gave such satisfactory results that the type of machinery was followed in the design of the latest steamer of the line, the steamer "Commonwealth". This steamer, which is one of the finest and best equipped boats of her type in the United States, is fully described in Transactions of the Society of Naval Architects and Marine Engineers, Vol. 16, 1908.

The turbine type of steamers is represented by the "Governor Cobb", the "Belfast" and the well-known steamers "Yale" and "Harvard". On comparison of the midship cross-section plans of these steamers, there will be noted a marked difference in the construction of the hulls, the "Governor Cobb" being fitted with a double bottom of the McIntyre type, the "Belfast" with light scantlings and single bottom, and the "Yale" and

"Harvard" with deep double bottoms. The steamers "Governor Cobb" and "Yale" and "Harvard" run practically the year round.

The "Governor Cobb" was built for a combination of outside and river service from Boston, Mass., to Bangor, Maine, and was afterwards engaged in service between Boston and St. John, New Brunswick, and in the winter months during the past few years has generally been in service between Florida and Havana, Cuba. She is a triple-screw steamer, having one high-pressure and two low-pressure Parsons turbines, two condensers and air pumps; the machinery is of the type of the first English Channel turbine steamers.

The "Belfast" is a triple-screw steamer of lighter loaded draft and is generally used on the route from Boston to Bangor, Maine, on the Penobscot River. Her machinery consists of one high-pressure and two low-pressure Parsons turbines, with single condenser, air pump, etc.

The "Yale" and "Harvard" are triple-screw steamers, with one high-pressure and two low-pressure Parsons turbines, two condensers, two air pumps, etc. They were built for the Metropolitan Steamship Company, for service from New York to Boston, a distance of about 300 nautical miles, and had a contract guarantee of an average speed of 20 knots between terminals, which they successfully accomplished. The "Yale" and "Harvard" are now in service between San Francisco and San Pedro, harbor of Los Angeles, California. Members are referred to a paper entitled "Service Test of the Steamship Harvard", Transactions of the Society of Naval Architects and Marine Engineers, Vol. 16, 1908.

HULL DETAILS.

Space permits of only a general characterization of the construction of the hulls, machinery and superstructures of the later-built boats. The plans give general hull details. Comparatively few of the River, Lake, Bay and Sound Steamers of the steamboat type are built under Classification Rules, such as Lloyds or American Bureau of Shipping, the owners adhering largely to the constructional details of their previous steamers and results obtained, and, in most cases, adopting the suggestions of their

architects and builders to suit demands of service. In recent years, however, the United States Steamboat Inspection Rules have exacted the filing and acceptance of all plans and details of construction of new vessels before issuing the first inspection papers. Except in cases of the large passenger boats of the Sound, Great Lakes and outside-service types, single bottoms are generally used. The plans give various types of double-bottom construction, dividing the double bottom into many watertight compartments, with pump connections. Joggle-shell plating has been extensively used rather than joggle framing, but the latter probably will be more generally adopted. Bulb angles, when readily obtainable from the rolling mills, have been largely used for frames, intercostals and deck beams, in the Hudson River, inland lake and bay steamers.

In recent years a greater amount of flanging, in lieu of angle bars, has been used for reverse frames, floors, intercostals, gussets and bulkheads. A system of longitudinal trussing from floors to main deck is very often used in the larger type of River steamers of the "Berkshire" class and the comparatively shallow-draft steamers of the inland-lake, "Horicon" type. The athwartship location of truss framing is as per plans shown. A deck beam on every frame is the usual practice. The guard beams of the paddle steamers are generally bracketed to the gunwale strake and secured to lodger plate, rather than extending the main-deck beams from outside to outside. Guard braces are usually of the truss-frame type, instead of the pipe or solid round-bar construction. Sponsons, as a rule, are used only on the larger type of paddle sound steamers; in screw steamers, the shell plating is formed to act as sponsons, where guards overhang. Main-deck plating is used over boiler, engine, auxiliary machinery and galley departments.

Generally, it can be stated that a greater number of watertight bulkheads, unpierced by doors, are used. There are two exits from each watertight compartment above floors, and a more extensive and reliable pumping system for watertight compartments is provided, with duplication of pumps on the main deck on the large steamers. There are a greater number of man-escape port holes through gunwale plating, and a more general use is made of bitumastic compositions, instead of cement, for

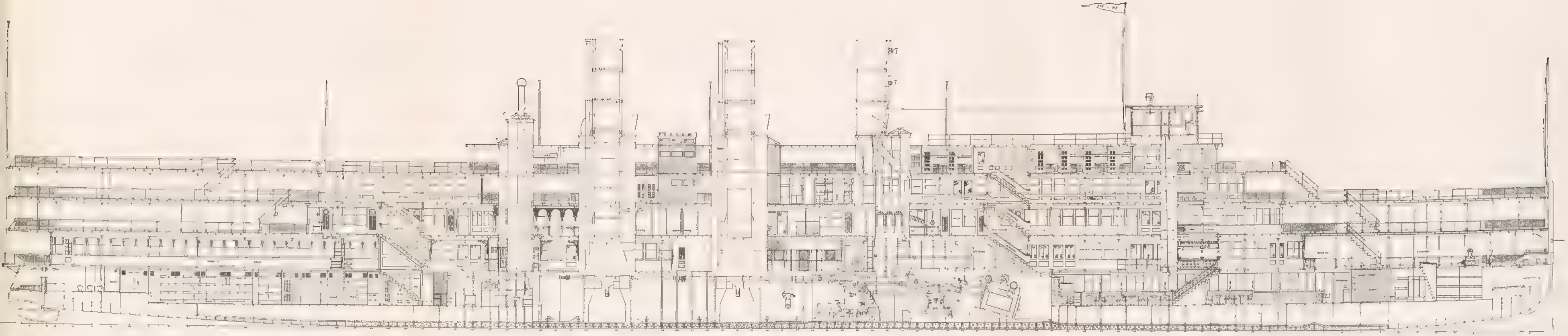
TABLE OF DATA

—ABBREVIATIONS—

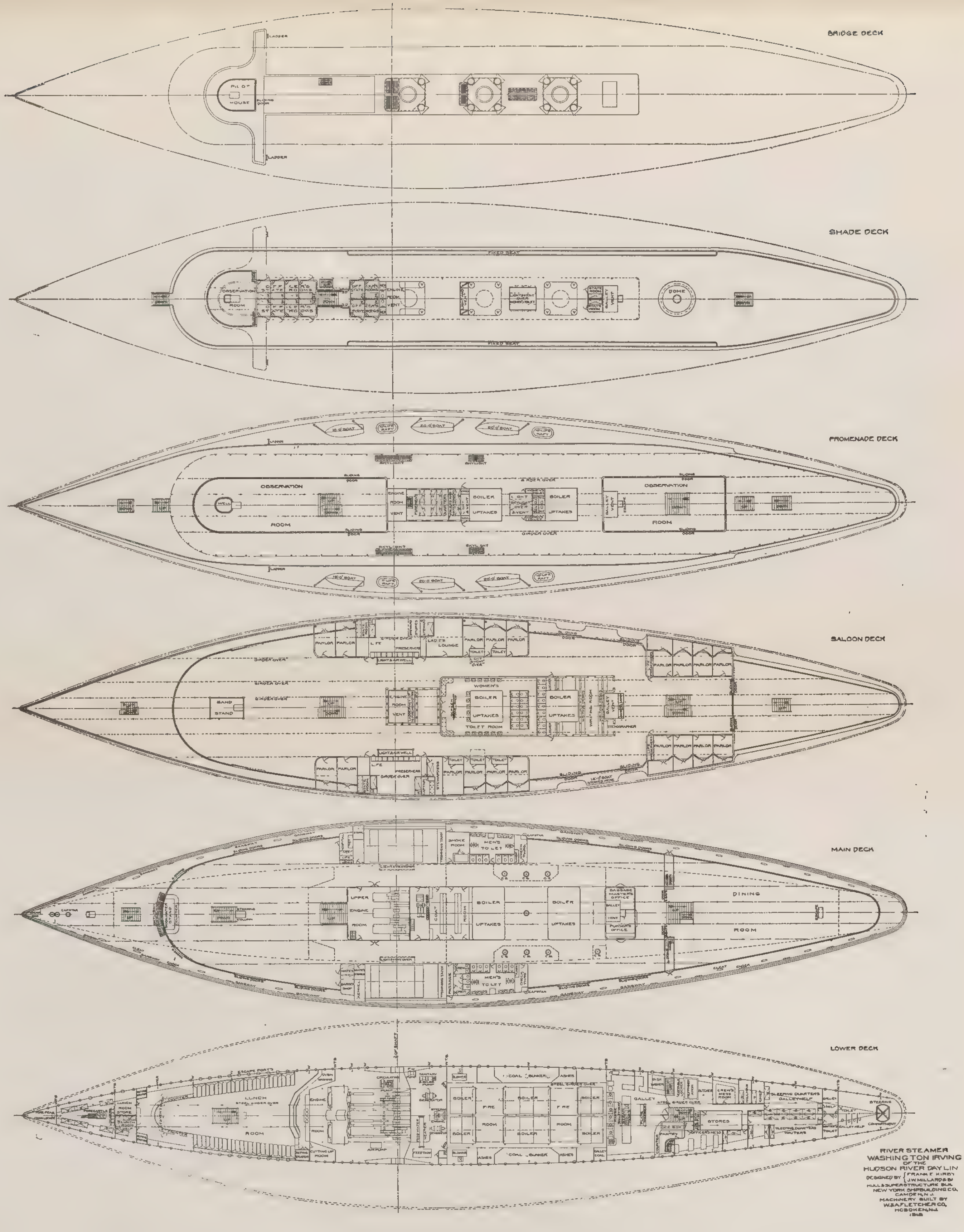
FLETCHER CO. = W.&A. FLETCHER CO.
H.&H. CORP. = HARLAN & HOLLINGSWORTH CORP.
N.Y.S.B.CO. = NEW YORK SHIPBUILDING CO.
D.R.I.S.B.&E.W. = DELAWARE RIVER IRON SHIPBUILDING & ENGINE WORKS.
S.C.&D.D.CO. = SEATTLE CONSTRUCTION & DRY DOCK CO.
DETROIT S.B.CO. = DETROIT SHIPBUILDING CO.

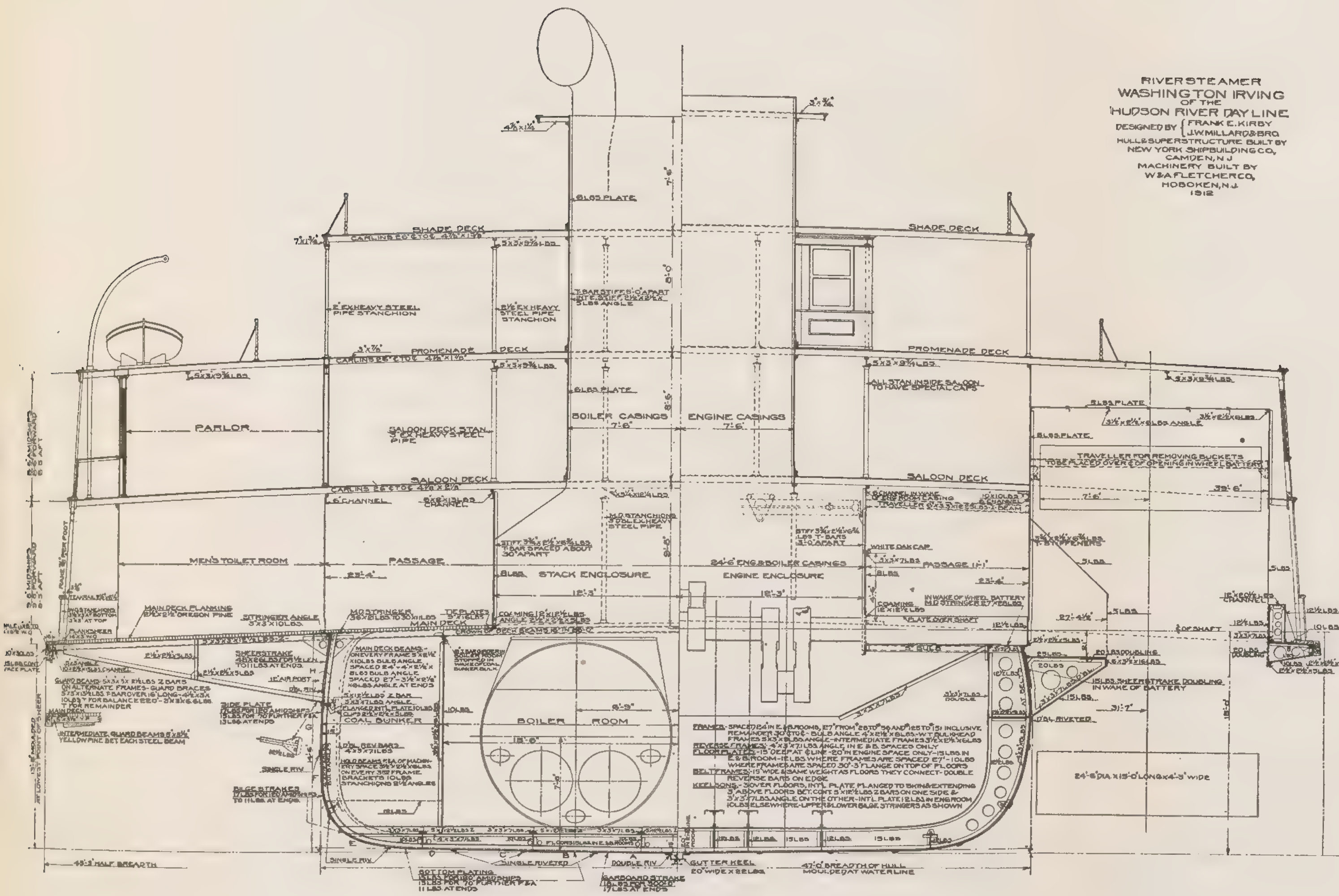
	WASHINGTON IRVING	BERKSHIRE	BENJAMIN B. ODELL	NORTHLAND	MARYLAND	ROSE STANDISH	PRISCILLA	BELFAST	YALE & HARVARD	GOVERNOR COBB	HORICON	SEEANDBEE	TACOMA
TYPE OF STEAMER	PADDLE	PADDLE	SCREW	SCREW	TWIN SCREW	PADDLE	PADDLE	TRIPLE SCREW	TRIPLE SCREW	TRIPLE SCREW	PADDLE	PADDLE	SCREW
SERVICE	RIVER	RIVER	RIVER	RIVER & BAY	BAY	BAY	SOUND & RIVER	RIVER & COAST	SOUND & COAST	RIVER & COAST	LAKE	GREAT LAKES	SOUND
CHARACTER OF SERVICE	PASSENGER	PASS. & FR'GT.	PASS. & FR'GT.	PASS. & FR'GT.	PASS. & FR'GT.	PASSENGER	PASS. & FR'GT.	PASS. & FR'GT.	PASS. & FR'GT.	PASS. & FR'GT.	PASSENGER	PASS. & FR'GT.	PASSENGER
DIMENSIONS:—													
LENGTH BET. PERPS.	396'-0"	420'-0"	270'-0"	297'-7"	249'-7"	205'-0"	421'-7"	318'-8"	384'-10"	289'-8"	220'-0"	485'-0"	215'-0"
LENGTH ON L.W.L.	407'-9"	421'-0"	261'-3"	293'-7"	255'-6"	204'-6"	423'-6"	320'-0"	386'-6"	291'-4"	219'-6"	486'-0"	218'-0"
LENGTH OVER ALL	412'-0"	437'-3"	280'-6"	305'-0"	259'-9¾"	215'-0"	440'-6"	335'-0"	403'-0"	301'-3"	230'-6"	500'-0"	221'-0"
BREADTH ON L.W.L.	47'-0"	50'-6"	40'-0"	42'-0"	37'-1"	34'-0"	52'-6"	40'-0"	50'-9"	50'-8"	33'-0"	58'-0"	30'-0"
BREADTH MOULDED AT M.D.	45'-8"	50'-6"	48'-9½"	51'-0"	40'-0"	34'-0"	52'-6"	40'-0"	60'-11"	53'-10"	33'-0"	53'-0"	30'-0"
BREADTH OVER GUARDS	86'-6"	88'-6"	49'-10½"	52'-6"	41'-11"	59'-0"	93'-0"	54'-2"	63'-0"	55'-2"	59'-0"	96'-0"	32'-0"
DEPTH MOULDED TO MAIN DECK	14'-6"	14'-5¾"	16'-3½"	17'-9"	15'-3½"	11'-9"	20'-6"	17'-0"	23'-9"	21'-3"	11'-1"	23'-6"	10'-0"
DRAFT, MEAN, ON TRIAL	8'-1"	8'-7½"	10'-0"	12'-2½"	10'-0½"	6'-4"	12'-10½"	9'-3"	14'-10½"	12'-6"	5'-9½"	14'-3½"	ABOUT 7'-6"
DISPLACEMENT ON TRIAL, GROSS TONS.	2200.-	3200.-	1390.-	1770.-	1250.-	686.-	4965.-	1824	4100	2420	610	5760	625
TRIAL SPEED IN STATUTE MILES PER HOUR	24.00	20.00	19.86	19.50	18.61	17.50	22.35	21.88	25.87	21.39	20.00	22.00	20.56
ENGINES:—													
NUMBER OF	ONE	ONE	ONE	ONE	TWO	ONE	TWO	THREE	THREE	THREE	ONE	ONE	ONE
TYPE	3 CYL. INCL. COMP.	BEAM	TRIP. EXP.	4 CYL. TRIP.	TRIP. EXP.	INCL. COMP.	INCL. COMP.	PARSON'S TURBINES	PARSON'S TURBINES	PARSON'S TURBINES	BEAM	3 CYL. INCL. COMP.	4 CYL. TRIP.
DIAMETER OF CYLINDERS	45"-70"-70"	84"	26"-41"-68"	23½-37-43-43	17-27½-44"	31"-56"	51"-95"				52"	66"-96"-96"	23-36½-42-42"
STROKE	84"	144"	36"	42"	26"	102"	132"				120"	108"	30"
HORSE POWER DEVELOPED ON TRIAL	6000	4200	2938	2488	1914	1500	9000.	SHAFT, 4575.	EST. 12200	EST. 5200	1550	9100	3300
BOILERS:—													
NUMBER OF	4 S.E. & 2 D.E.	FOUR	FOUR	FOUR	FOUR	TWO	TEN	FOUR	TWELVE	SIX	TWO	6 S.E. & 3 D.E.	TWO
TYPE	SCOTCH	LOBSTER BACK	SCOTCH	SCOTCH	SCOTCH	SCOTCH	SCOTCH	SCOTCH	SCOTCH	SCOTCH	LOBSTER BACK	SCOTCH	WATER TUBE
DIAMETER	S.E. 12'-4" D.E. 12'-4"	9'-6"	13'-0"	12'-6"	12'-0"	13'-0"	14'-0"	14'-6"	14'-0"	13'-6"	9'-0½"	S.E. 14'-0" D.E. 14'-2"	BALLIN
LENGTH	S.E. 11'-3¼" D.E. 22'-2"	33'-4"	11'-2¾"	11'-3"	11'-6"	12'-7"	14'-6"	12'-0¾"	12'-0"	11'-8"	26'-0"	S.E. 10'-6" D.E. 20'-5½"	
WIDTH		11'-10"									10'-6"		
TOTAL GRATE SURFACE IN SQ. FT.	410.	352.	202.	228.	195.	147.	825.	264.	756.	390.	135.	594.	OIL BURNING
TOTAL HEATING SURFACE IN SQ. FT.	16720.	8200.	7936.	7980.	7324.	4872.	22000.	11340.	29500.	13518.	3890.	25452.	11000
WORKING PRESSURE IN LBS.	170	55	180	180	180	133	150	150	155	150	53	165	250
SYSTEM OF DRAUGHT	HOWDEN'S	FORCED—UNDER GRATE	HOT AIR-FORCED	NATURAL	NATURAL	FORCED—UNDER GRATE	FORCED—UNDER GRATE	ELLIS & EAVES FORCED	HOWDEN'S	FORCED—UNDER GRATE	FORCED—UNDER GRATE	HOWDEN'S	NATURAL
GENERAL CONTRACTORS	OWNERS.	FLETCHER CO.	H.&H. CORP.	H.&H. CORP.	MARYLAND STEEL CO.	FLETCHER CO.	FLETCHER CO.	BATH IRON WORKS	FLETCHER CO.	FLETCHER CO.	FLETCHER CO.	DETROIT S.B.CO.	S.C.&D.D.CO.
HULL BUILDERS	N.Y.S.B.CO.	N.Y.S.B.CO.	" "	" "	" " "	H.&H. CORP.	D.R.I.S.B.&E.W.	" " "	D.R.I.S.B.&E.W.	D.R.I.S.B.&E.W.	T.S. MARVEL S.B.CO.	" " "	" " " " " "
ENGINE BUILDERS	FLETCHER CO.	FLETCHER CO.	" "	" "	" " "	FLETCHER CO.	FLETCHER CO.	" " "	FLETCHER CO.	FLETCHER CO.	FLETCHER CO.	" " "	" " " " " "
NAVAL ARCHITECTS	FRANK E. KIRBY J.W. MILLARD & BRO.	FLETCHER CO. J.W. MILLARD & BRO.	" "	" "	" " "	FLETCHER CO. J.W. MILLARD & BRO.	GEORGE PEIRCE	" " "	FLETCHER CO. WM. DENNY & BRO.	FLETCHER CO. WM. DENNY & BRO.	FLETCHER CO. J.W. MILLARD & BRO.	" " "	" " " " " "
JOINER WORK.	N.Y.S.B.CO.	C.M. ENGLIS.	" "	" "	" "	C.M. ENGLIS.	W^M. ROWLAND.	" " "	C.M. ENGLIS.	C.M. ENGLIS.	LAKE GEORGE S.B.CO.	" " "	" " " " " "

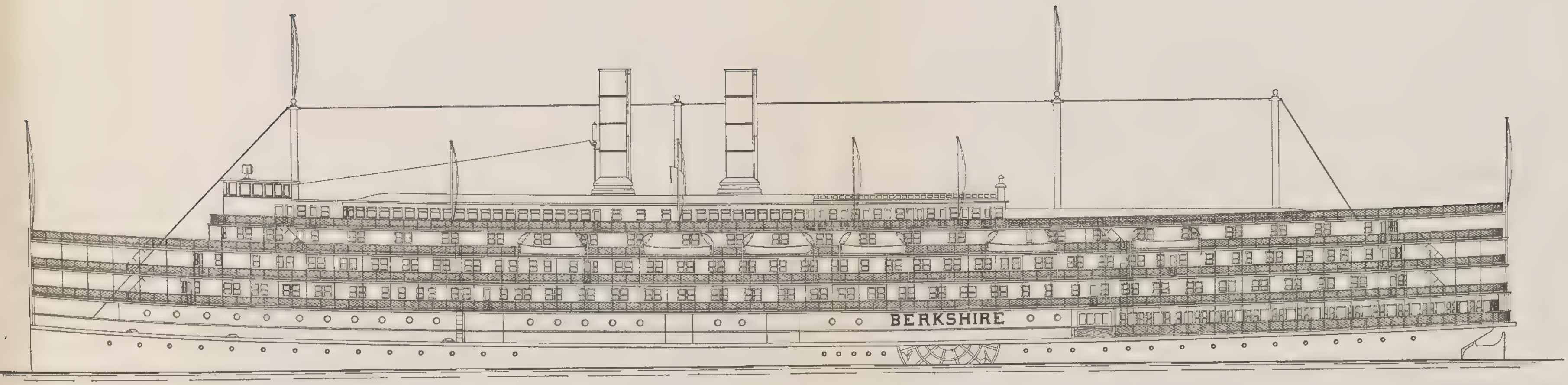
Andrew Fletcher.
Hoboken, N.J. 1915.



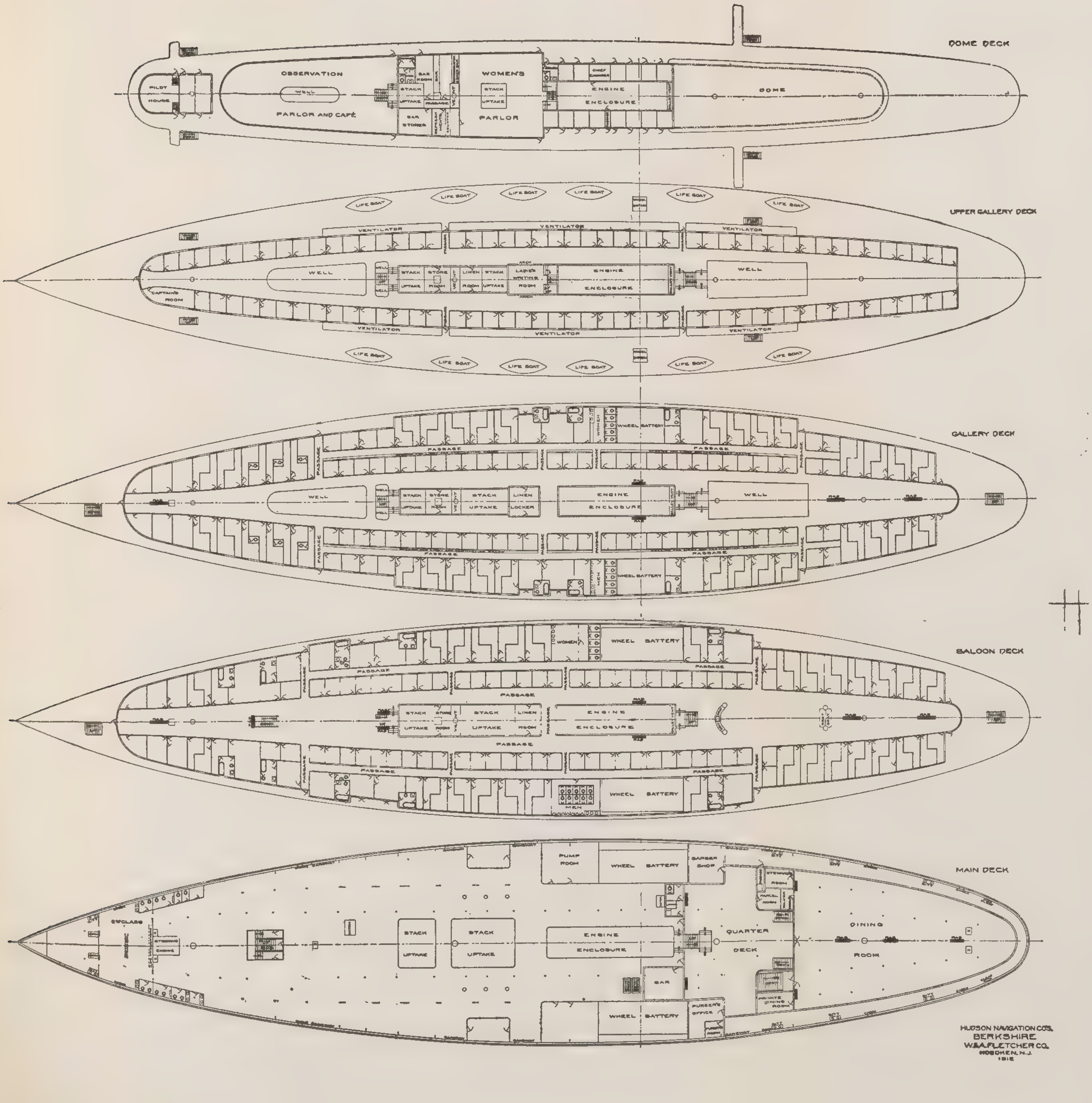
RIVER STEAMER
WASHINGTON IRVING
OF THE
HUDSON RIVER DAY LINE
DESIGNERS: FRANK E. KIRBY
J. W. MILLARD & BRO.
HULL & SUPERSTRUCTURE BUILT BY
NEW YORK SHIPBUILDING CO.
CAMDEN N.J.
MACHINERY BUILT BY
W. & A. FLETCHER CO.
HOBOKEN N.J.

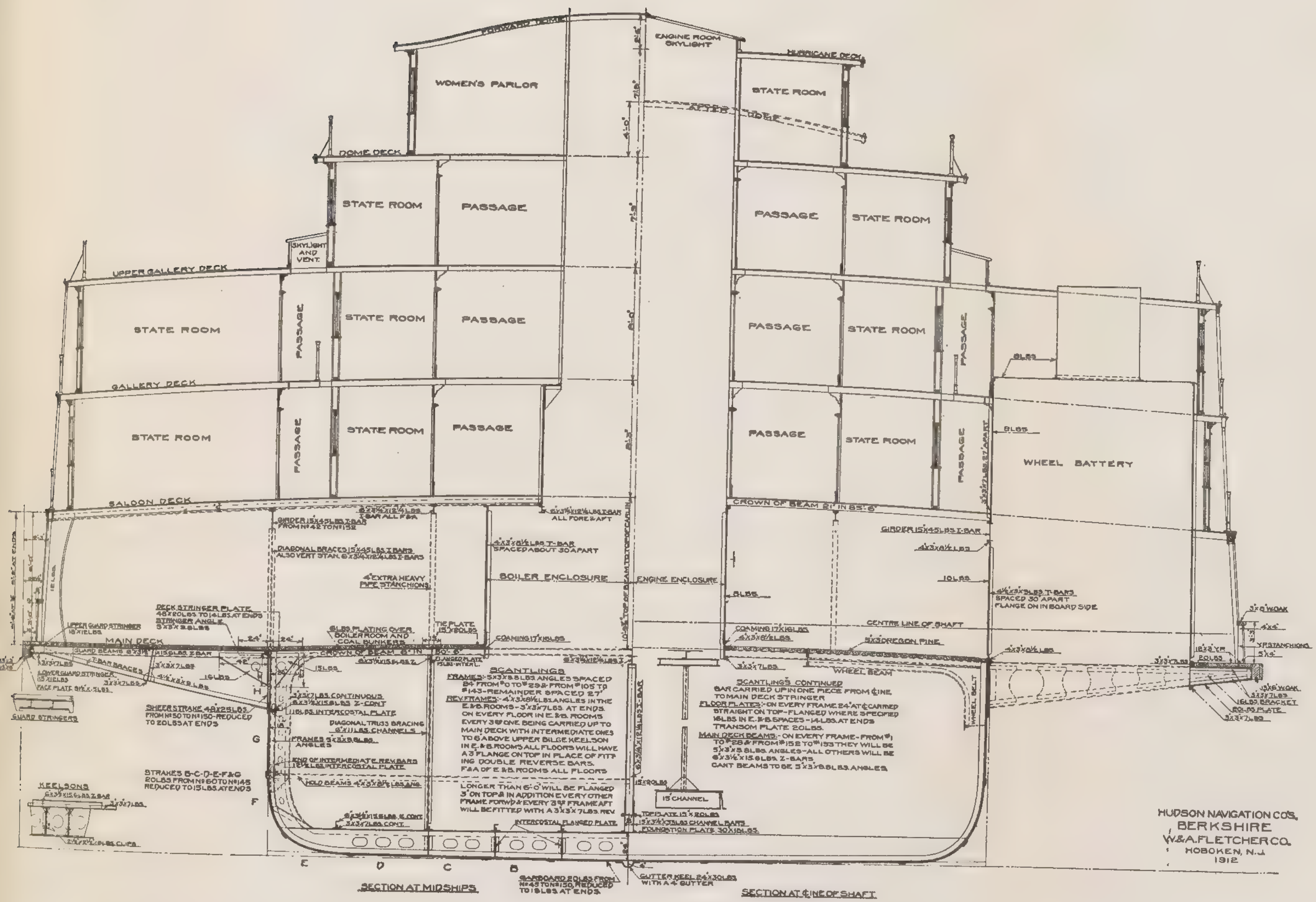

BRIDGE DECK
SHADE DECK
PROMENADE DECK
SALOON DECK
MAIN DECK
LOWER DECK
RIVER STEAMER
WASHINGTON IRVING
OF THE
HUDSON RIVER DAY LIN
DESIGNED BY FRANK E. KIRBY
J.W. MILLARD & BR
HULL & SUPERSTRUCTURE BUIL
NEW YORK SHIPBUILDING CO.
CAMDEN, N.J.
MACHINERY BUILT BY
W. & A. FLETCHER CO.
HOBOKEN, N.J.


RIVER STEAMER
WASHINGTON IRVING
OF THE
HUDSON RIVER DAY LINE
DESIGNED BY FRANK E. KIRBY
J.W. MILLARD & BRO.
HULL & SUPERSTRUCTURE BUILT BY
NEW YORK SHIPBUILDING CO,
CAMDEN, N J
MACHINERY BUILT BY
W & A FLETCHER CO,
HOBOKEN, N.J.
1912
SHADE DECK
PROMENADE DECK
SALOON DECK
MAIN DECK
PARLOR
MEN'S TOILET ROOM
PASSAGE
STACK ENCLOSURE
ENGINE ENCLOSURE
BOILER CASINGS
ENGINE CASINGS
BOILER ROOM
COAL BUNKER
TRAVELLER FOR REMOVING BUCKETS
GUTTER KEEL
47'-0" BREADTH OF HULL MOULDED AT WATER LINE
45'-2" HALF BREADTH

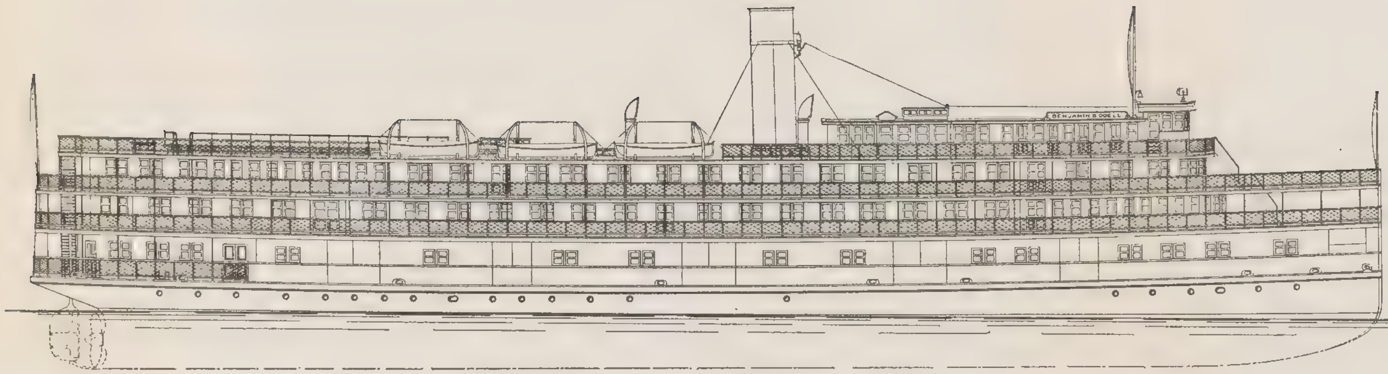


HUDSON NAVIGATION CO'S,
BERKSHIRE
W.&A.FLETCHER CO.
HOBOKEN, N.J.
1912

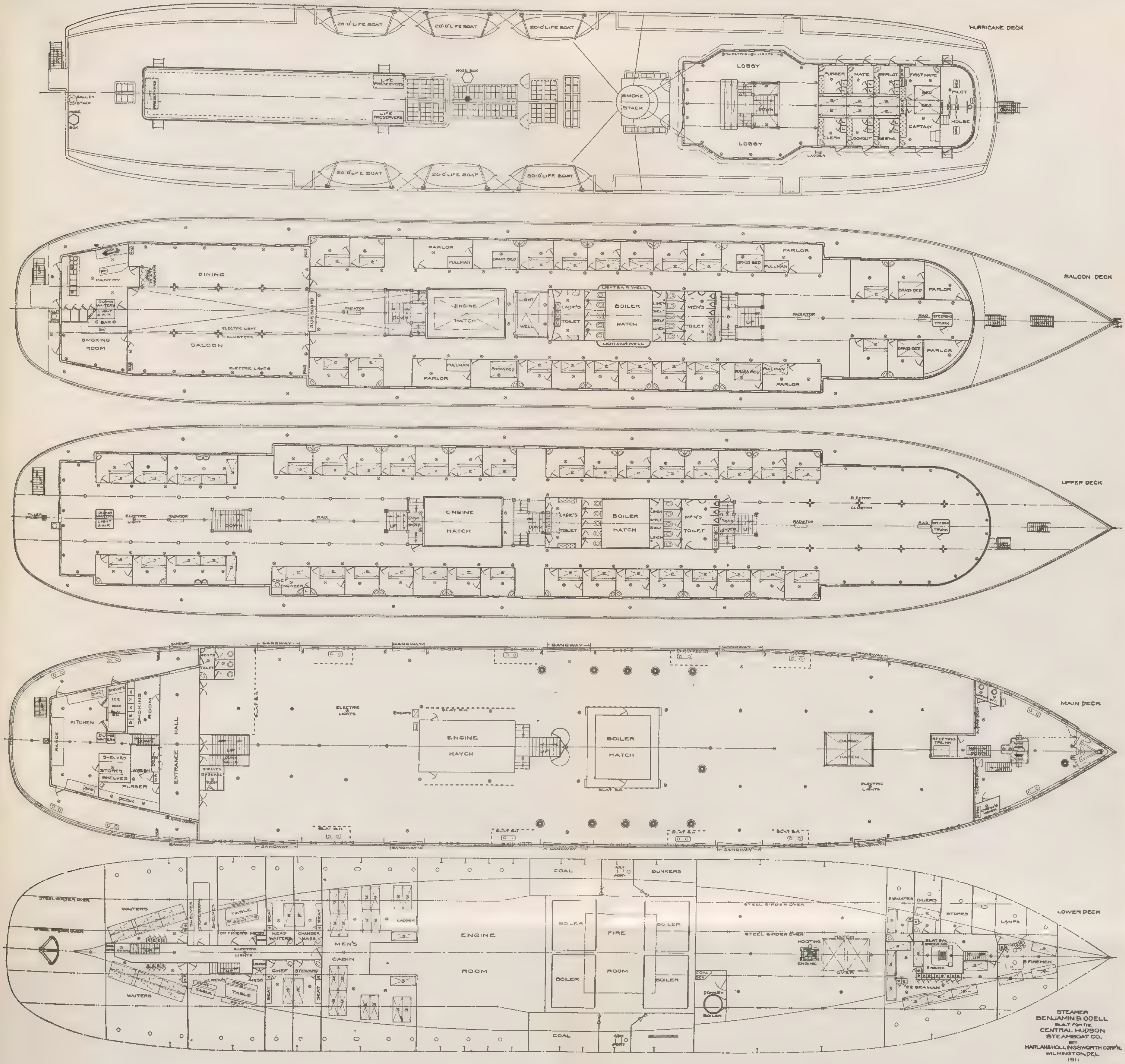

DOME DECK
PILOT HOUSE
OBSERVATION
WELL
PARLOR AND CAFÉ
BAR ROOM
STACK
UPTAKE
PASSAGE
BAR STORES
WOMEN'S
PARLOR
CHIEF ENGINEER
ENGINE
ENCLOSURE
DOME
UPPER GALLERY DECK
LIFE BOAT
VENTILATOR
CAPTAIN'S ROOM
WELL
STACK
STORE
UPTAKE
ROOM
LINEN
ROOM
LADIES WRITING ROOM
ARCH
ENGINE
ENCLOSURE
GALLERY DECK
PASSAGE
WOMEN
WHEEL BATTERY
LINEN
LOCKER
MEN
SALOON DECK
WOMEN
WHEEL BATTERY
PASSAGE
MEN
MAIN DECK
PUMP ROOM
WHEEL BATTERY
BARBER SHOP
STACK
UPTAKE
ENGINE
ENCLOSURE
QUARTER DECK
DINING ROOM
PARCEL ROOM
BAR
PRIVATE DINING ROOM
PURSER'S OFFICE
HUDSON NAVIGATION CO'S.
BERKSHIRE
W.&A.FLETCHER CO.
HOBOKEN, N.J.
1912

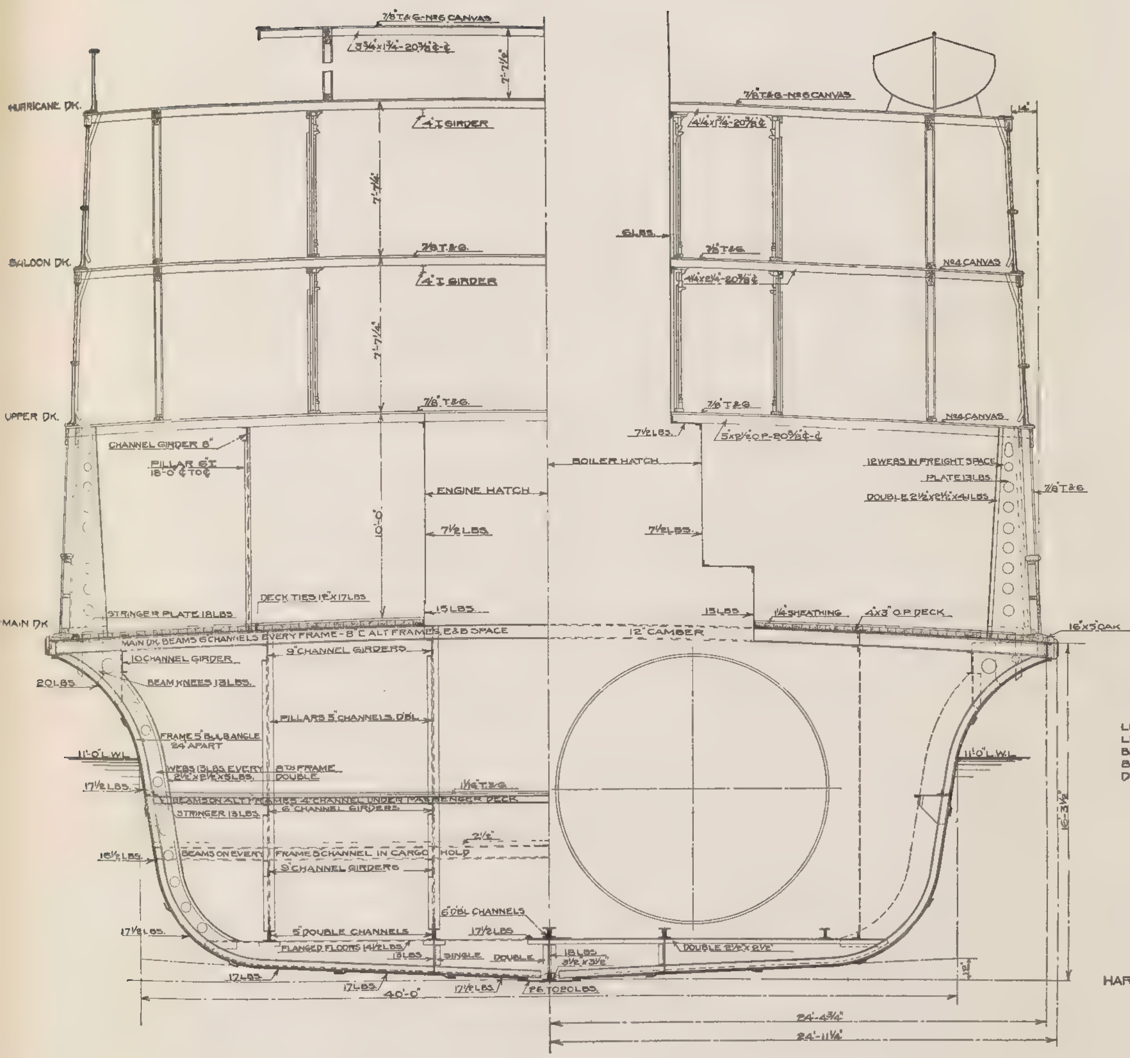


ENGINE ROOM SKYLIGHT
HURRICANE DECK
WOMEN'S PARLOR
STATE ROOM
DOME DECK
PASSAGE
SKYLIGHT AND VENT.
UPPER GALLERY DECK
GALLERY DECK
WHEEL BATTERY
SALOON DECK
CROWN OF BEAM 21" IN 85'-6"
BOILER ENCLOSURE
ENGINE ENCLOSURE
CENTRE LINE OF SHAFT
MAIN DECK
WHEEL BEAM
SCANTLINGS
SCANTLINGS CONTINUED
15 CHANNEL
GUARD STRINGERS
KEELSONS
SECTION AT MIDSHIPS
SECTION AT ℄ INE OF SHAFT
HUDSON NAVIGATION COS.
BERKSHIRE
W.&A.FLETCHER CO.
HOBOKEN, N.J.
1912



STEAMER
BENJAMIN B. ODELL
BUILT FOR THE
CENTRAL HUDSON
STEAMBOAT CO.
BY
HARLAN & HOLLINGSWORTH CORP'N.,
WILMINGTON, DEL
1911

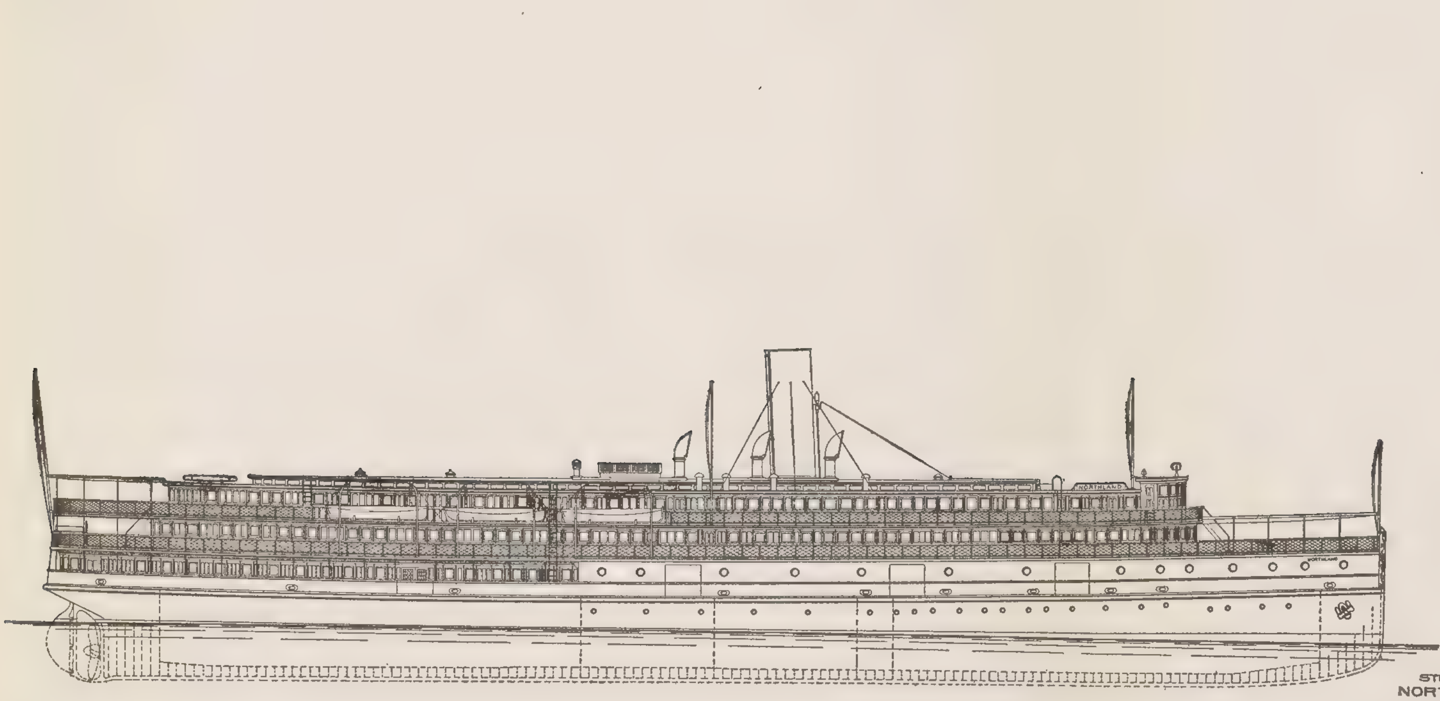

HURRICANE DECK
SALOON DECK
UPPER DECK
MAIN DECK
LOWER DECK
STEAMER
BENJAMIN B. ODELL
BUILT FOR THE
CENTRAL HUDSON
STEAMBOAT CO.
BY
HARLAN & HOLLINGSWORTH CORP'N.
WILMINGTON, DEL.
1911



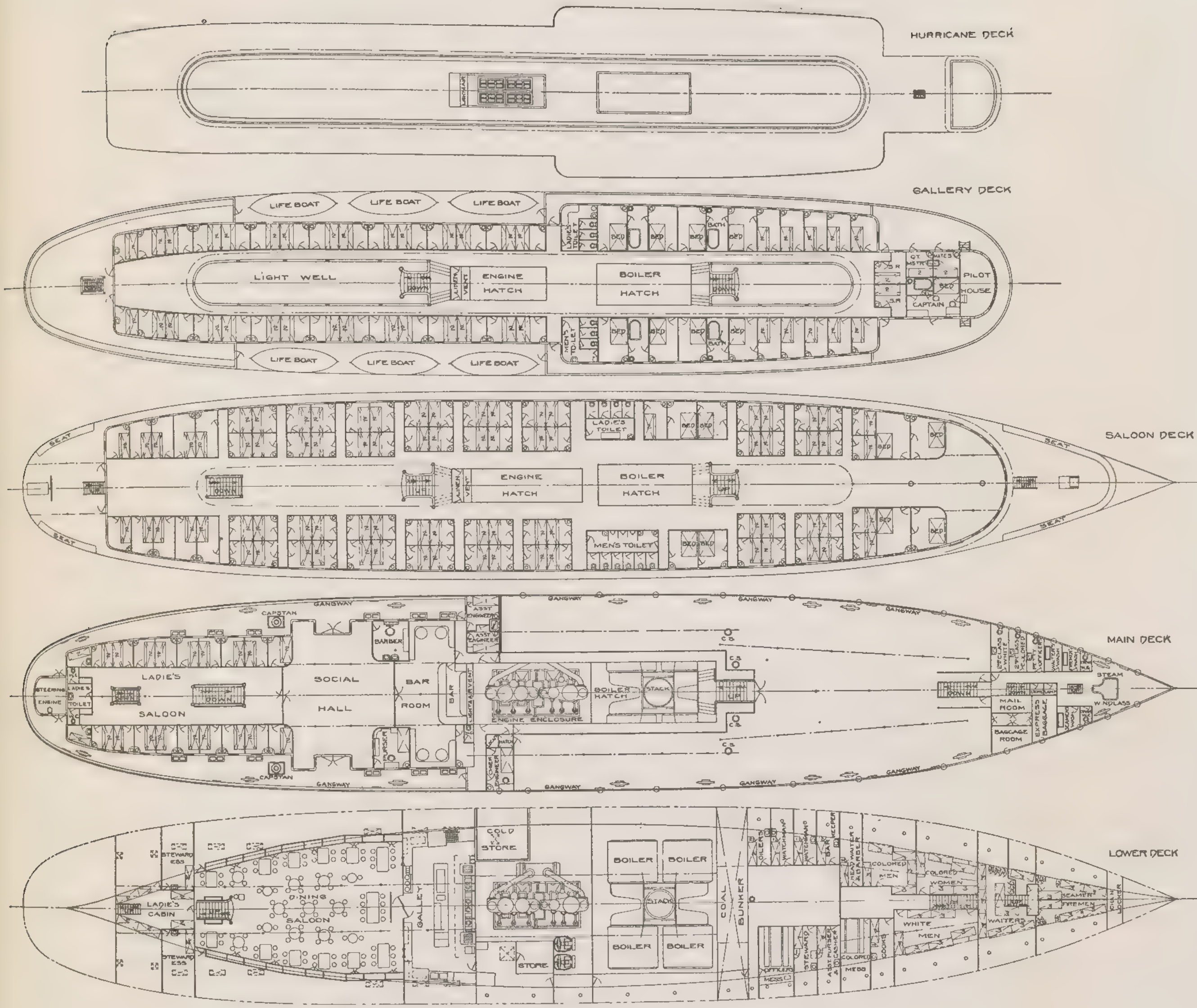
DIMENSIONS

LENGTH OVER ALL	280'-6"
LENGTH BET PERPS.	270'-0"
BREADTH OVER ALL	49'-10½"
BREADTH MOULDED	48'-9½"
DEPTH MOULDED	16'-3½"

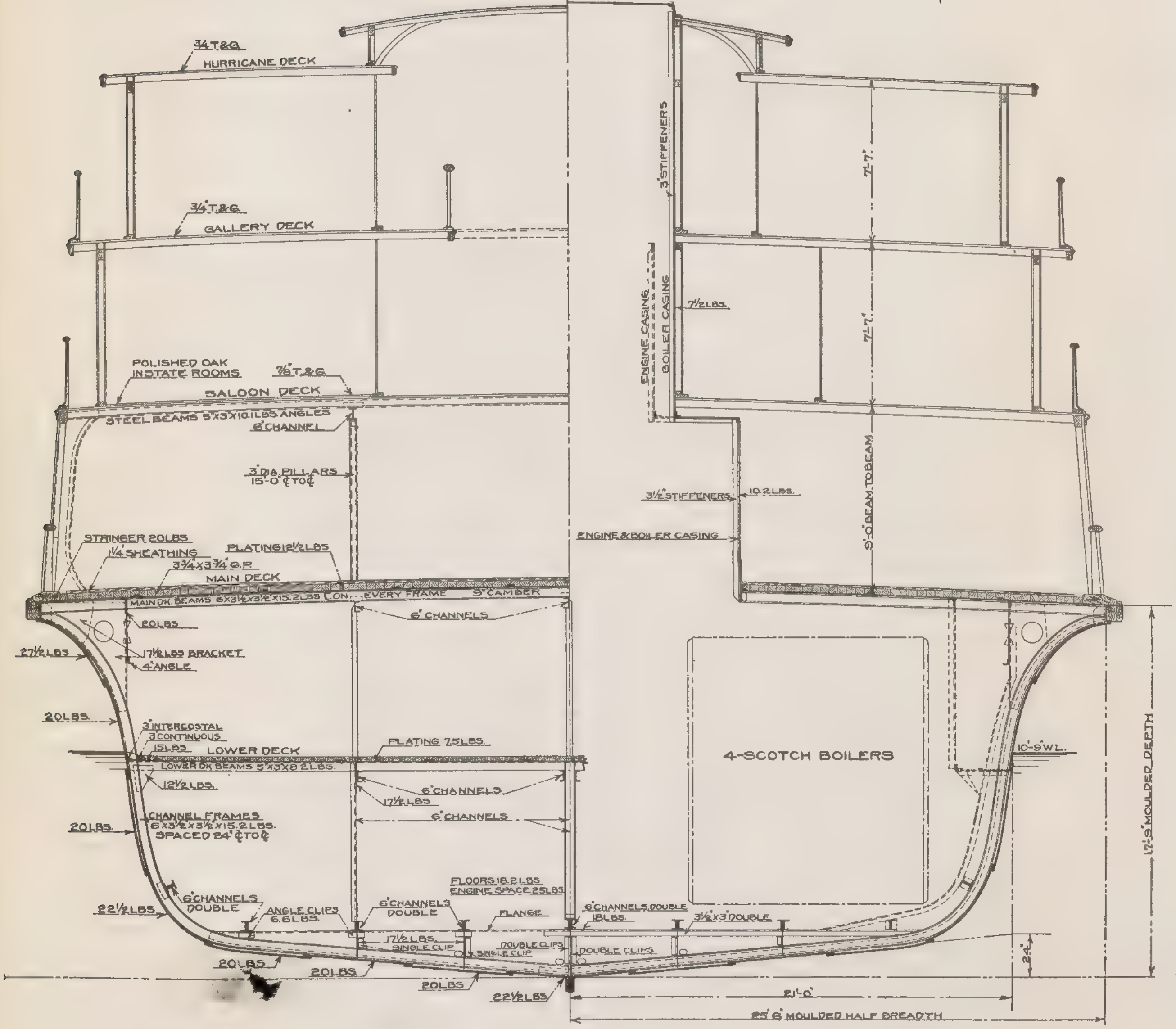
STEAMER
BENJAMIN B. ODELL
BUILT FOR THE
CENTRAL HUDSON
STEAMBOAT CO.,
BY
HARLAN & HOLLINGSWORTH CORP'N.,
WILMINGTON, DEL.
1911



STEAMER
NORTHLAND
BUILT FOR THE
NORFOLK & WASHINGTON
STEAMBOAT CO.,
BY
HARLAN & HOLLINGSWORTH CORP'N,
WILMINGTON, DEL.
1911



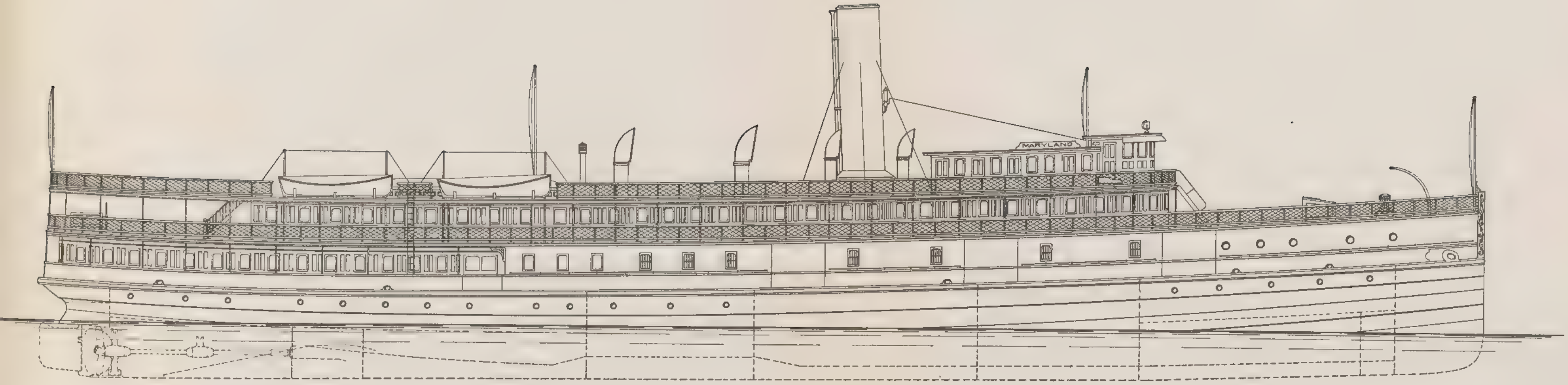
STEAMER
NORTHLAND
BUILT FOR THE
NORFOLK & WASHINGTON
STEAMBOAT CO.
BY
HARLAN & HOLLINGSWORTH CORP'N.,
WILMINGTON, DEL
1911



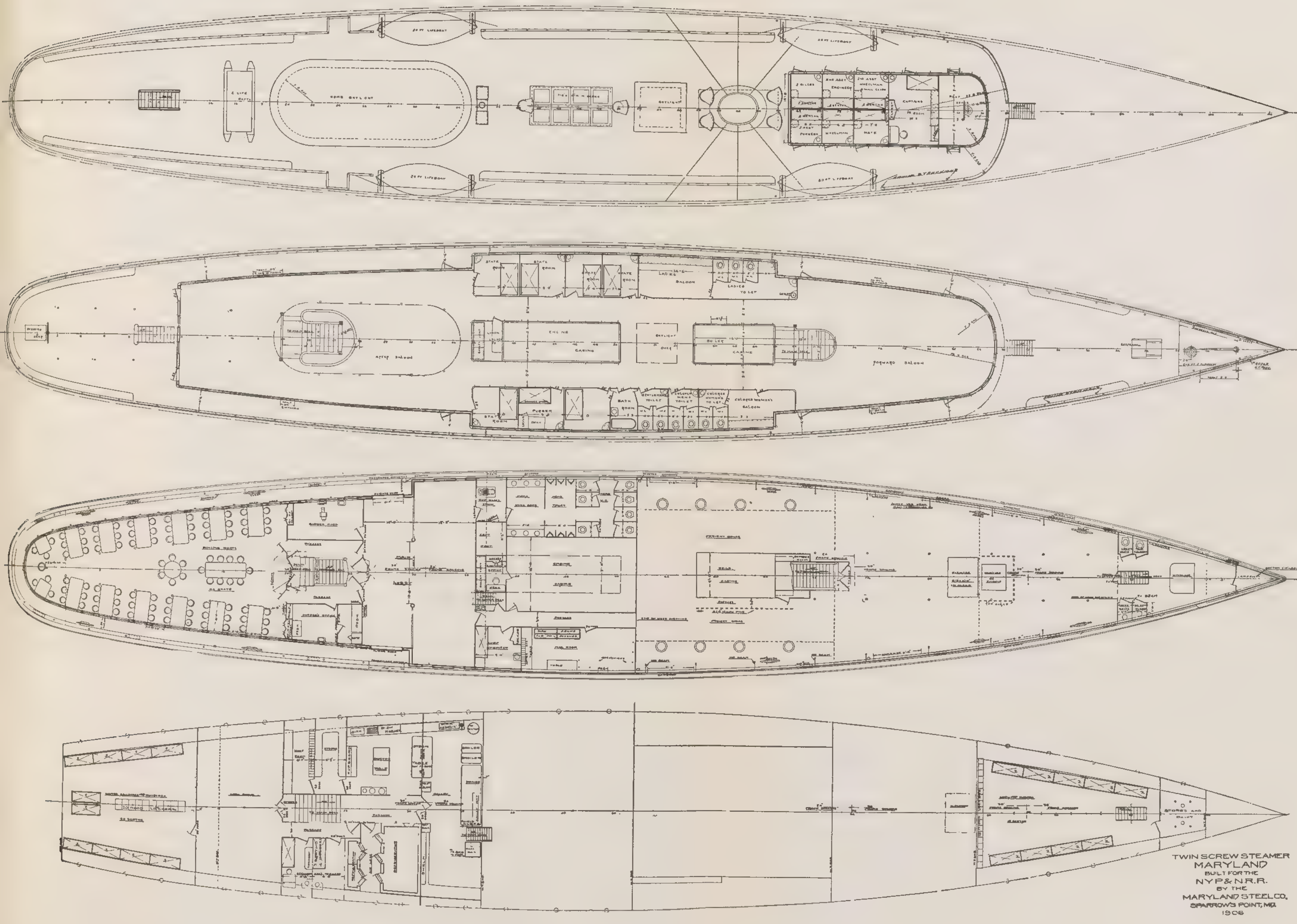
GENERAL DIMENSIONS

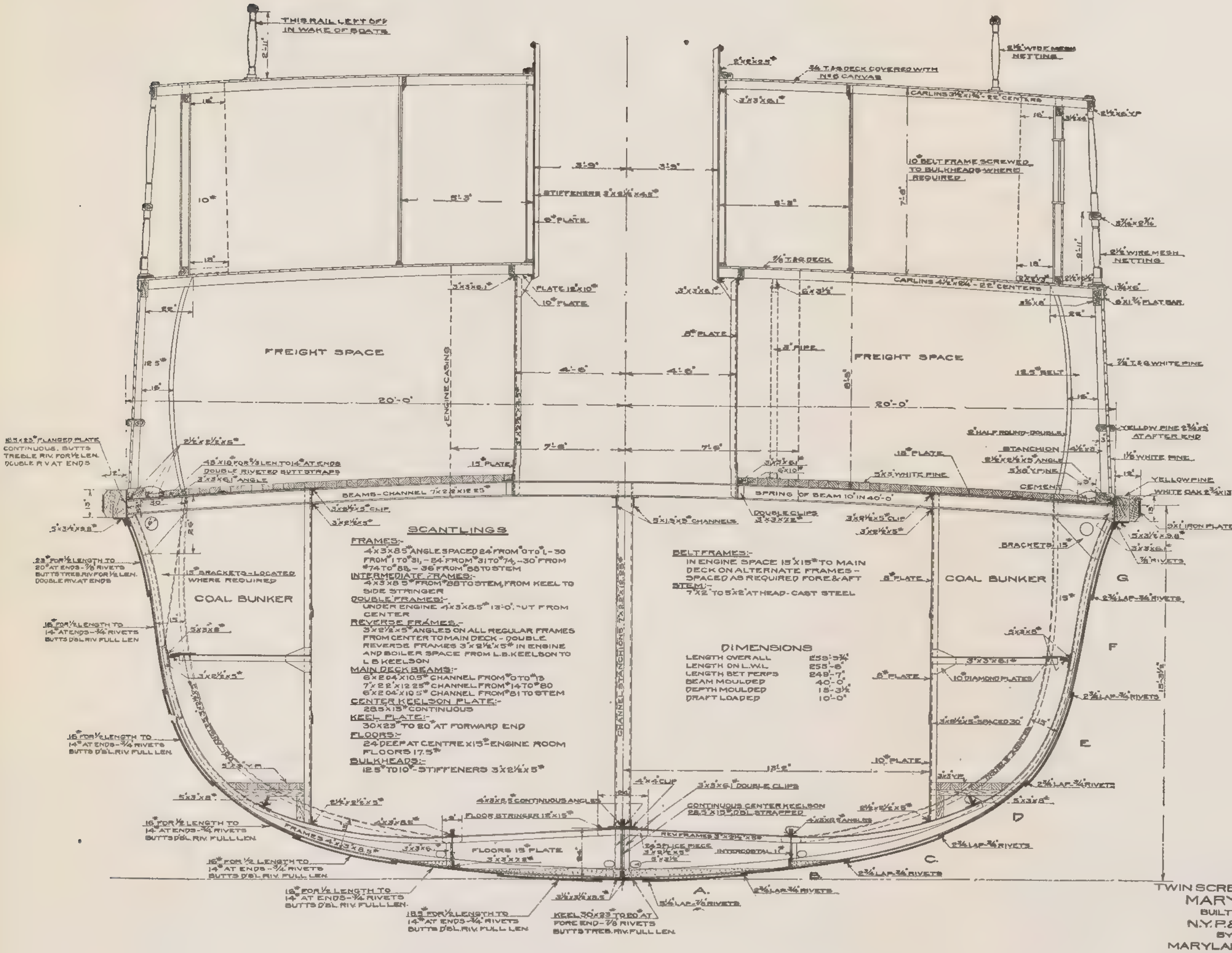
LENGTH BET. PERPS.	297'-7"
BREADTH AT MAIN DK. M'L'D.	51'-0"
DEPTH MOULDED	17'-9"

STEAMER
NORTHLAND
BUILT FOR THE
NORFOLK & WASHINGTON
STEAMBOAT CO.,
BY
HARLAN & HOLLINGSWORTH CORP'N.,
WILMINGTON, DEL.
1911

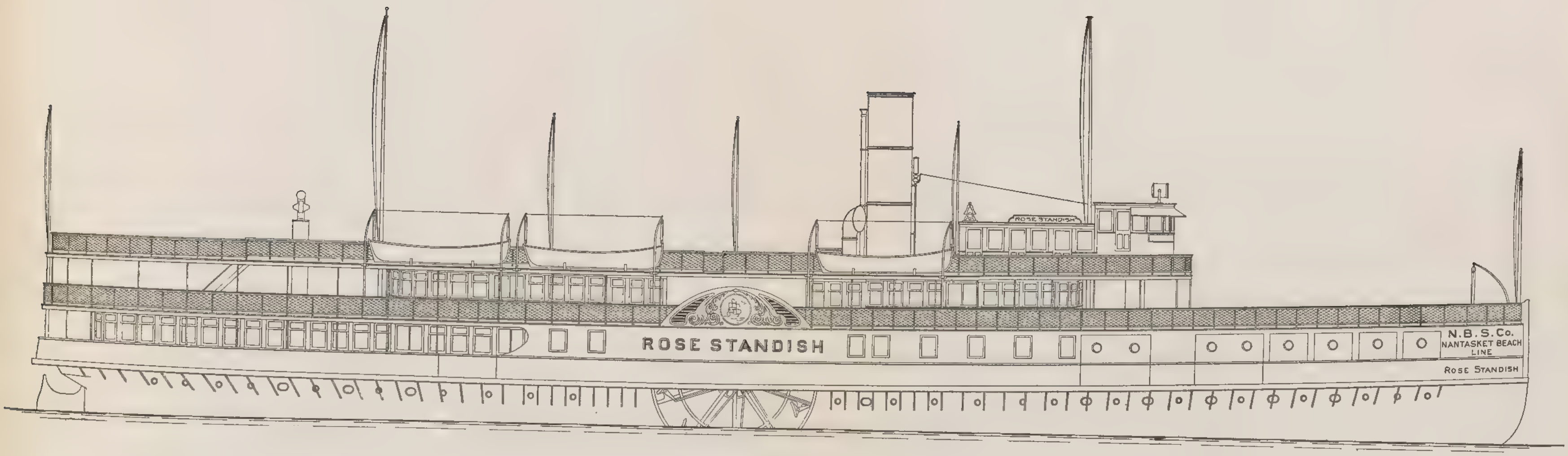


TWIN SCREW STEAMER
MARYLAND
BUILT FOR THE
N.Y.P. & N.R.R.
BY THE
MARYLAND STEEL CO,
SPARROW'S POINT, MD.
1906

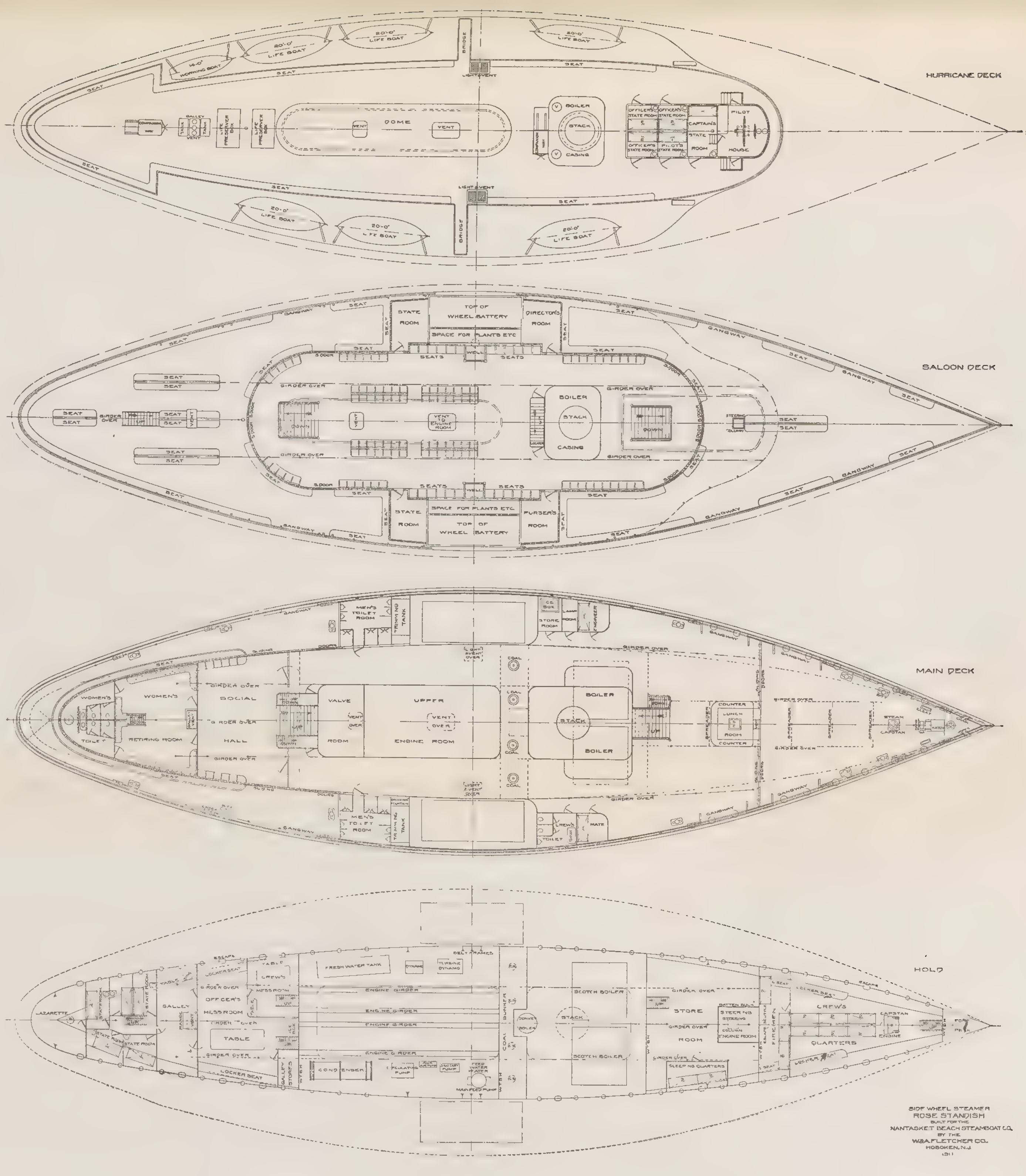

TWIN SCREW STEAMER
MARYLAND
BUILT FOR THE
NYP& N.R.R.
BY THE
MARYLAND STEEL CO.
SPARROW'S POINT, MD.
1906

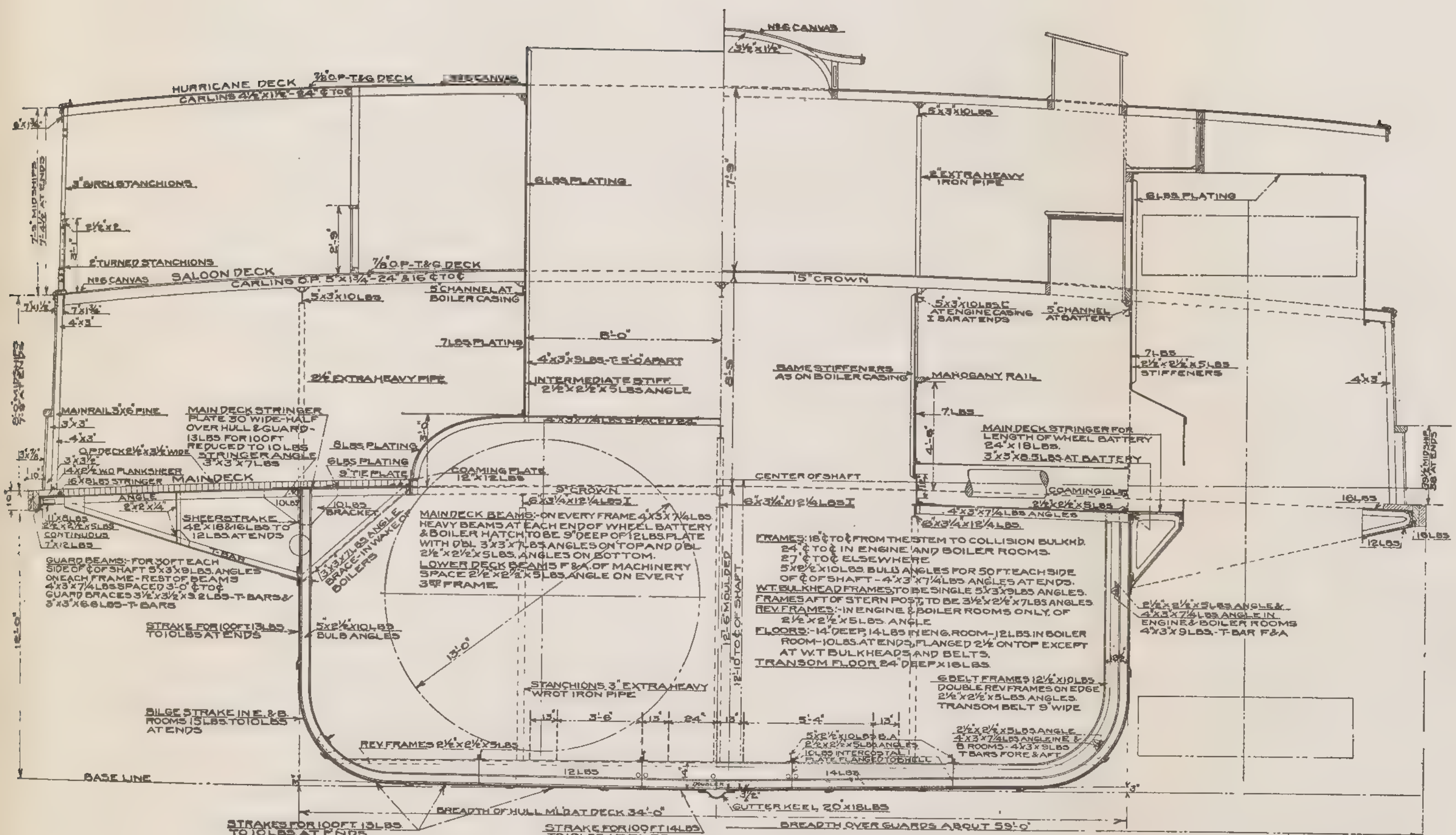


TWIN SCREW STEAMER
MARYLAND
BUILT FOR THE
N.Y.P.& N.R.R.
BY THE
MARYLAND STEEL CO.
SPARROWS POINT, MD.
1906

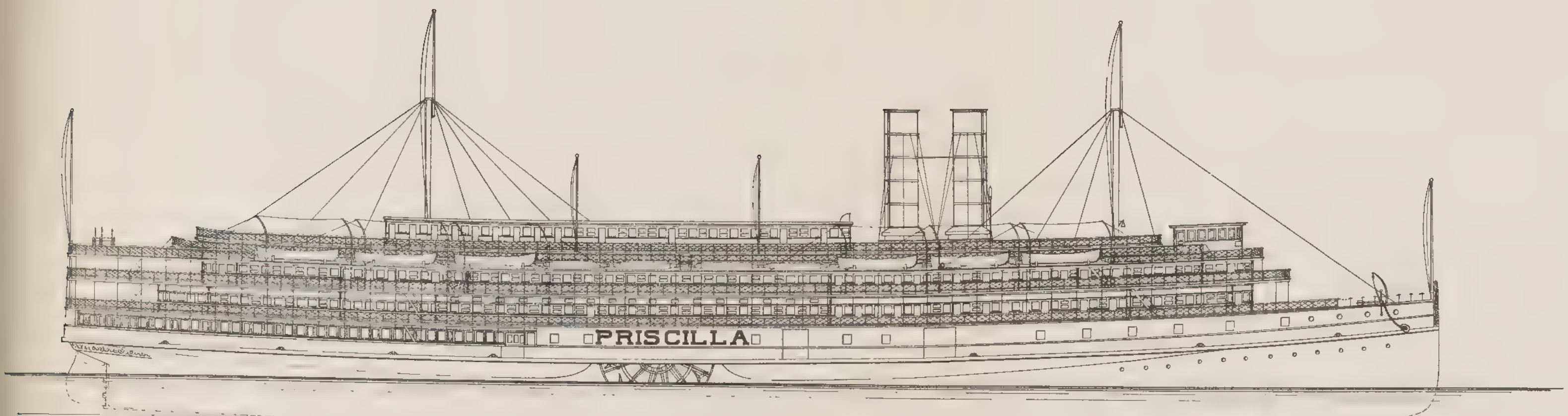


SIDE WHEEL STEAMER
ROSE STANDISH
BUILT FOR THE
NANTASKET BEACH STEAMBOAT CO.
BY THE
W.&A. FLETCHER CO.
HOBOKEN, N.J.
1911


HURRICANE DECK
SALOON DECK
MAIN DECK
HOLD
PILOT HOUSE
CAPTAIN'S STATE ROOM
BOILER
STACK
CASING
DOME
VENT
LIFE PRESERVER BOX
GALLEY
TANK
BRIDGE
LIGHT & VENT
20-0" LIFE BOAT
16-0" WORKING BOAT
SEAT
GANGWAY
STATE ROOM
TOP OF WHEEL BATTERY
SPACE FOR PLANTS ETC.
DIRECTOR'S ROOM
PURSER'S ROOM
SEATS
GIRDER OVER
DOWN
WOMEN'S TOILET
WOMEN'S RETIRING ROOM
SOCIAL HALL
VALVE ROOM
UPPER ENGINE ROOM
COAL
LUNCH ROOM
COUNTER
STEAM CAPSTAN
MEN'S TOILET ROOM
STORE ROOM
ENGINEER
MATE
UP
LAZARETTE
OFFICER'S MESSROOM
TABLE
CREW'S MESSROOM
LOCKER SEAT
GALLEY STORES
FRESH WATER TANK
ENGINE GIRDER
CONDENSER
COAL BUNKER
SCOTCH BOILER
STORE ROOM
STEERING ENGINE ROOM
SLEEPING QUARTERS
FIREMEN
CREWS QUARTERS
CAPSTAN ENGINE
SIDE WHEEL STEAMER
ROSE STANDISH
BUILT FOR THE
NANTASKET BEACH STEAMBOAT CO.
BY THE
W.&A. FLETCHER CO.
HOBOKEN, N.J.
1911

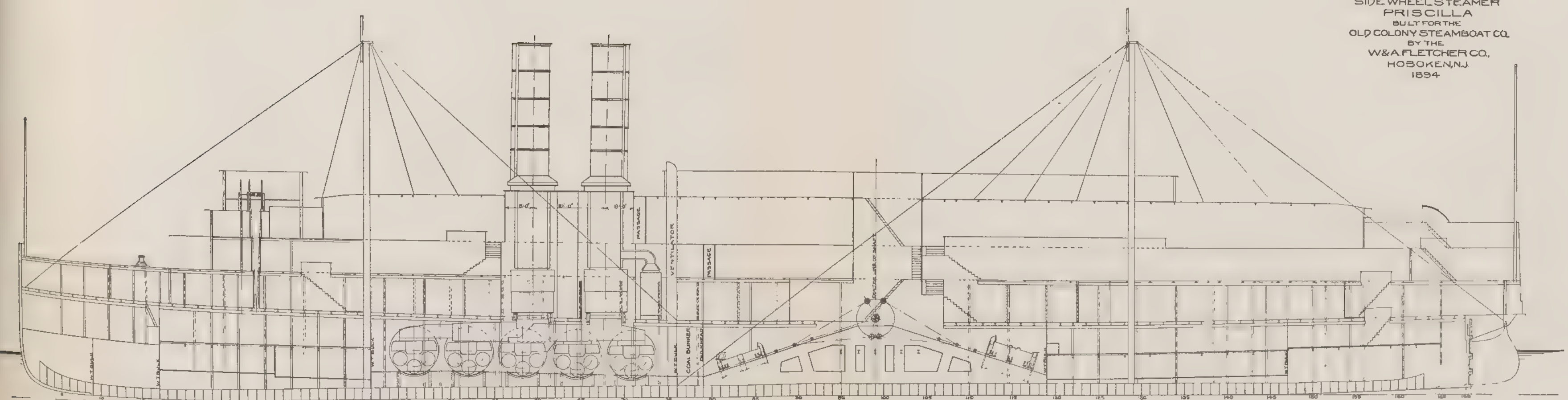


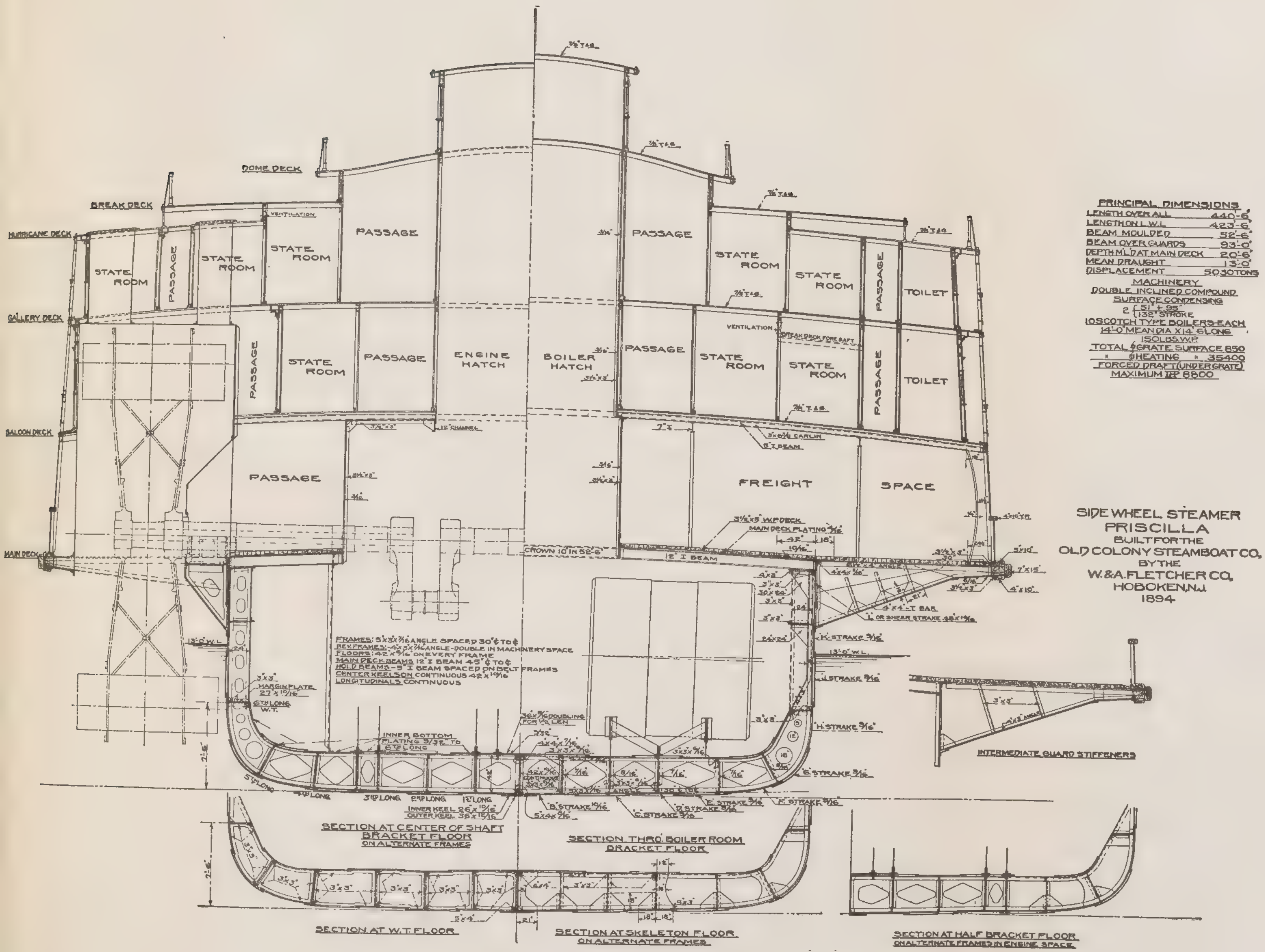
SIDE WHEEL STEAMER
ROSE STANDISH
BUILT FOR THE
NANTASKET BEACH STEAMBOAT CO
BY THE
W.&A. FLETCHER CO.,
HOBOKEN, N.J
1911



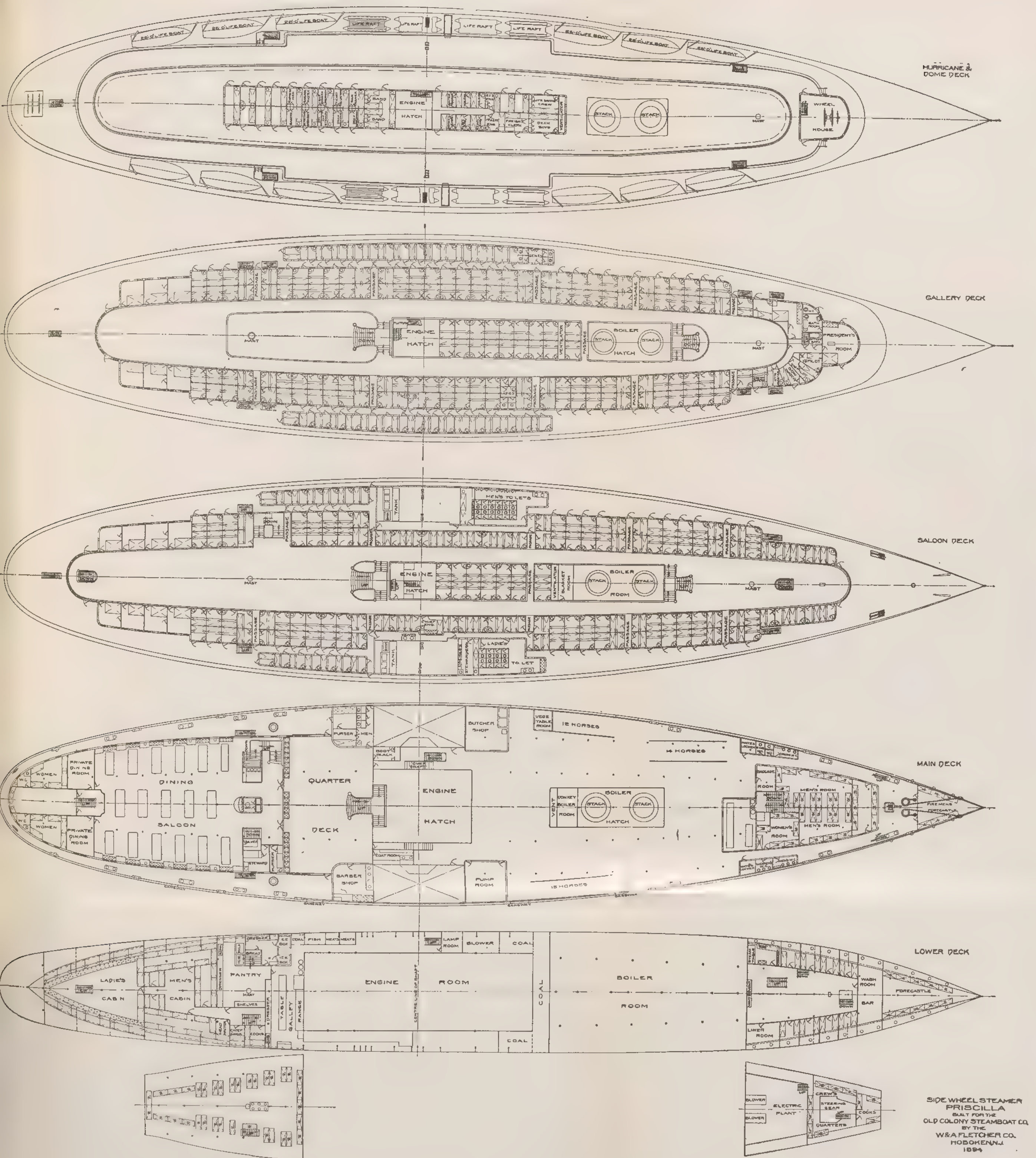
SIDE WHEEL STEAMER
PRISCILLA
BUILT FOR THE
OLD COLONY STEAMBOAT CO.,
BY THE
W.&A. FLETCHER CO.,
HOBOKEN, N.J.
1894

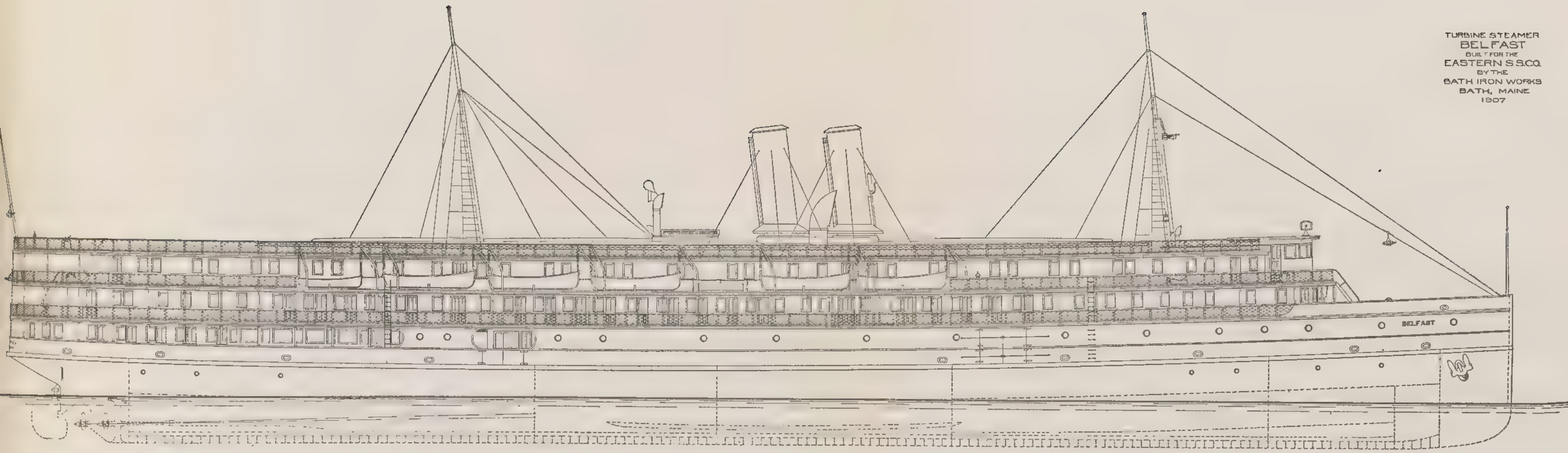
SKELETON
LONGITUDINAL SECTION
SIDE WHEEL STEAMER
PRISCILLA
BUILT FOR THE
OLD COLONY STEAMBOAT CO.
BY THE
W.&A. FLETCHER CO.
HOBOKEN, N.J.
1894



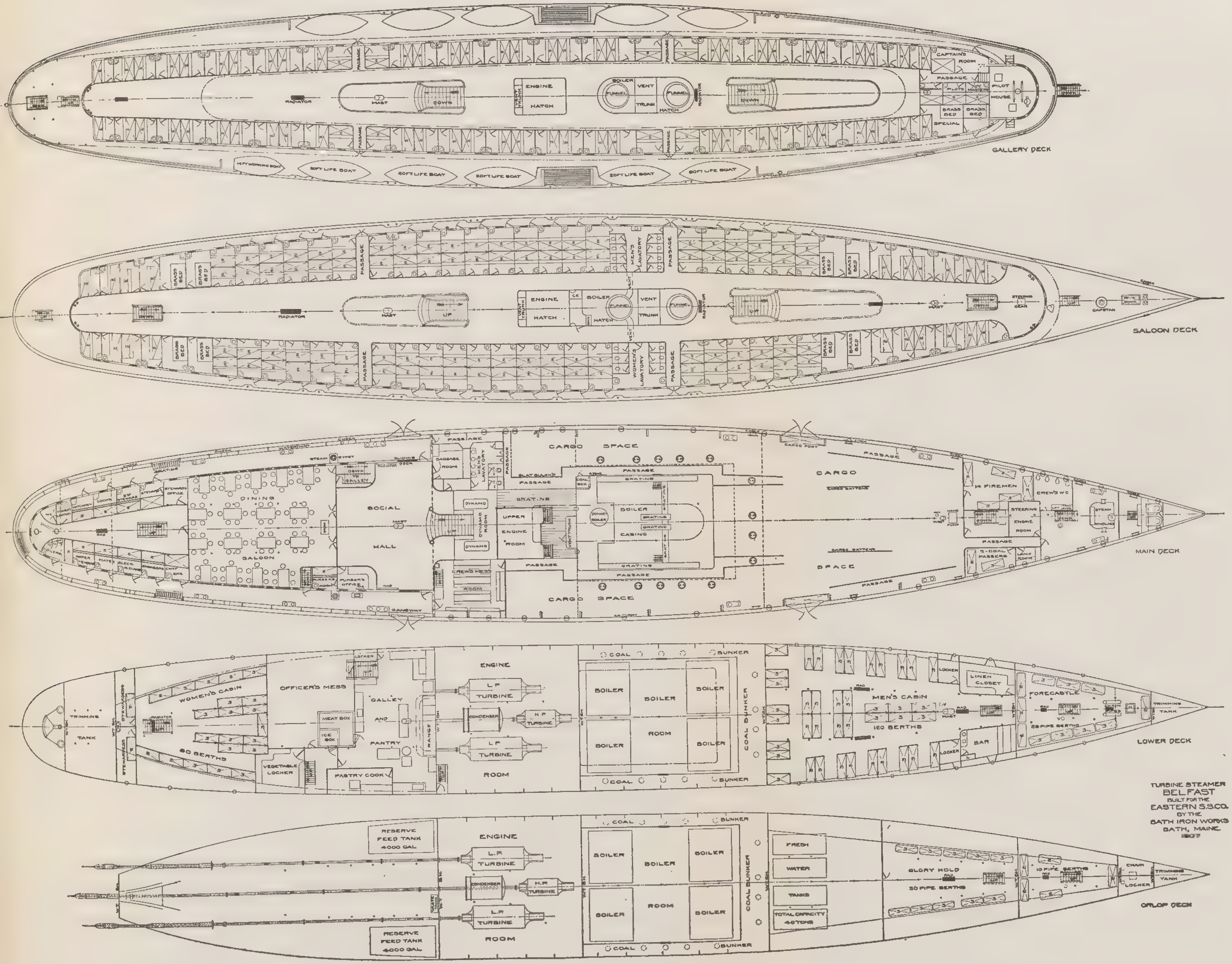


DOME DECK
BREAK DECK
HURRICANE DECK
GALLERY DECK
SALOON DECK
MAIN DECK
STATE ROOM
PASSAGE
ENGINE HATCH
BOILER HATCH
TOILET
FREIGHT
SPACE
PRINCIPAL DIMENSIONS
LENGTH OVER ALL 440'-6"
LENGTH ON L.W.L. 423'-6"
BEAM MOULDED 52'-6"
BEAM OVER GUARDS 93'-0"
DEPTH M'LD AT MAIN DECK 20'-6"
MEAN DRAUGHT 13'-0"
DISPLACEMENT 5030 TONS
MACHINERY
DOUBLE INCLINED COMPOUND
SURFACE CONDENSING
2 (51" + 95") (132" STROKE
10 SCOTCH TYPE BOILERS-EACH
14'-0" MEAN DIA X 14' 6" LONG
150 LBS. W.P.
TOTAL GRATE SURFACE 850
" HEATING " 35400
FORCED DRAFT (UNDER GRATE)
MAXIMUM I.H.P. 8500
SIDE WHEEL STEAMER
PRISCILLA
BUILT FOR THE
OLD COLONY STEAMBOAT CO.
BY THE
W. & A. FLETCHER CO.
HOBOKEN, N.J.
1894
CROWN 10 IN 52'-6"
12" I BEAM
INNER BOTTOM
INTERMEDIATE GUARD STIFFENERS
SECTION AT CENTER OF SHAFT
BRACKET FLOOR
ON ALTERNATE FRAMES
SECTION THRO' BOILER ROOM
BRACKET FLOOR
SECTION AT W.T. FLOOR
SECTION AT SKELETON FLOOR
ON ALTERNATE FRAMES
SECTION AT HALF BRACKET FLOOR
ON ALTERNATE FRAMES IN ENGINE SPACE

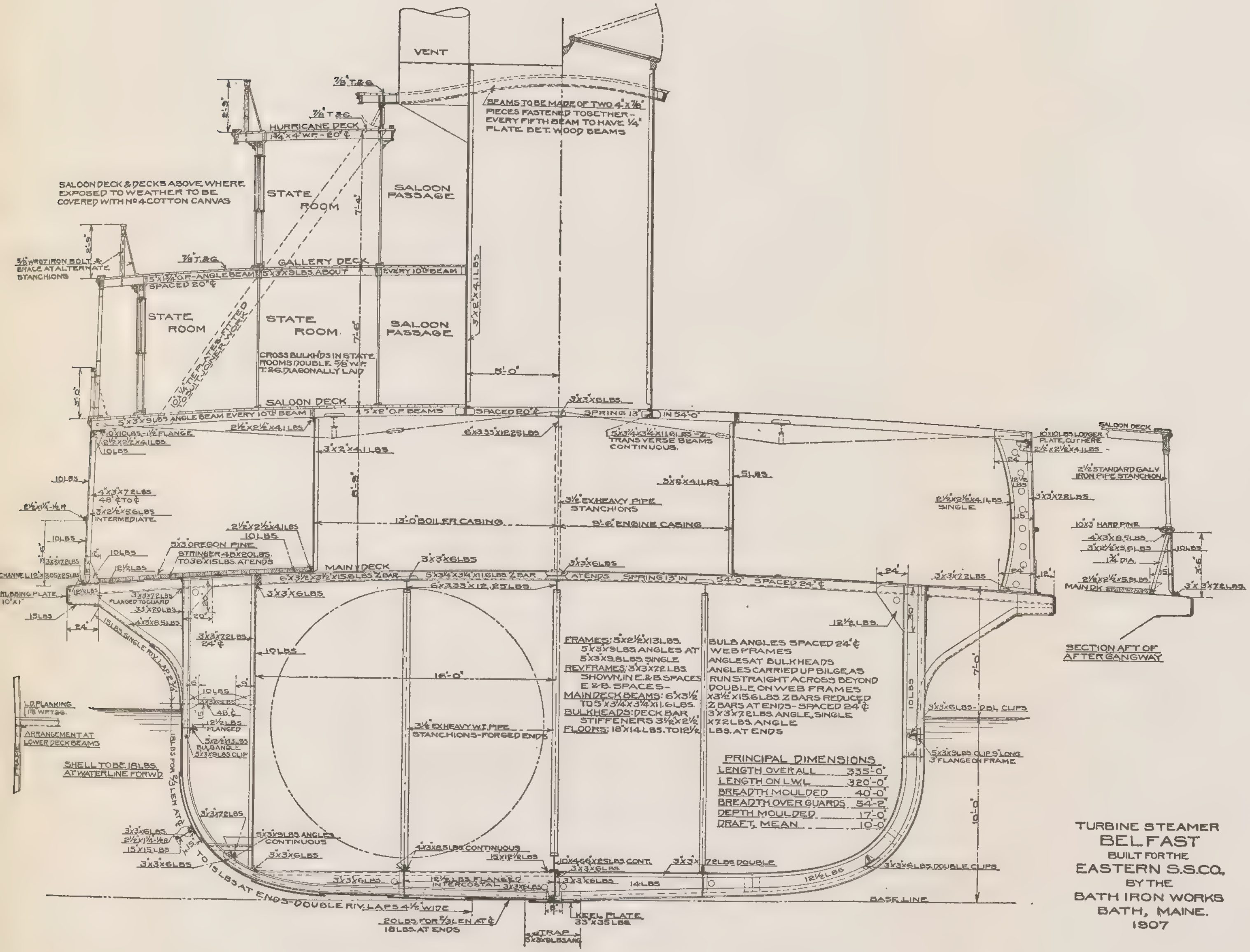

HURRICANE & DOME DECK
GALLERY DECK
SALOON DECK
MAIN DECK
LOWER DECK
LIFE RAFT
ENGINE HATCH
STACK
STACK
WHEEL HOUSE
MAST
BOILER HATCH
PRESIDENT'S ROOM
PASSAGE
MEN'S TOILETS
TANK
LADIES'
TO LET
BOILER ROOM
DINING SALOON
PRIVATE DINING ROOM
WOMEN
QUARTER DECK
ENGINE HATCH
BUTCHER SHOP
PURSER
12 HORSES
14 HORSES
18 HORSES
BARBER SHOP
PUMP ROOM
DONKEY BOILER ROOM
MEN'S ROOM
WOMEN'S ROOM
FIREMENS FORECASTLE
LADIE'S CABIN
MEN'S CABIN
PANTRY
GALLEY
TABLE
RANGE
ENGINE ROOM
CENTRE LINE OF SHAFT
LAMP ROOM
BLOWER
COAL
BOILER ROOM
WASH ROOM
FORECASTLE
BAR
LINEN ROOM
ELECTRIC PLANT
CREW'S QUARTERS
STEERING GEAR
COOKS
SIDE WHEEL STEAMER
PRISCILLA
BUILT FOR THE
OLD COLONY STEAMBOAT CO.
BY THE
W.&A.FLETCHER CO.
HOBOKEN,N.J.
1894



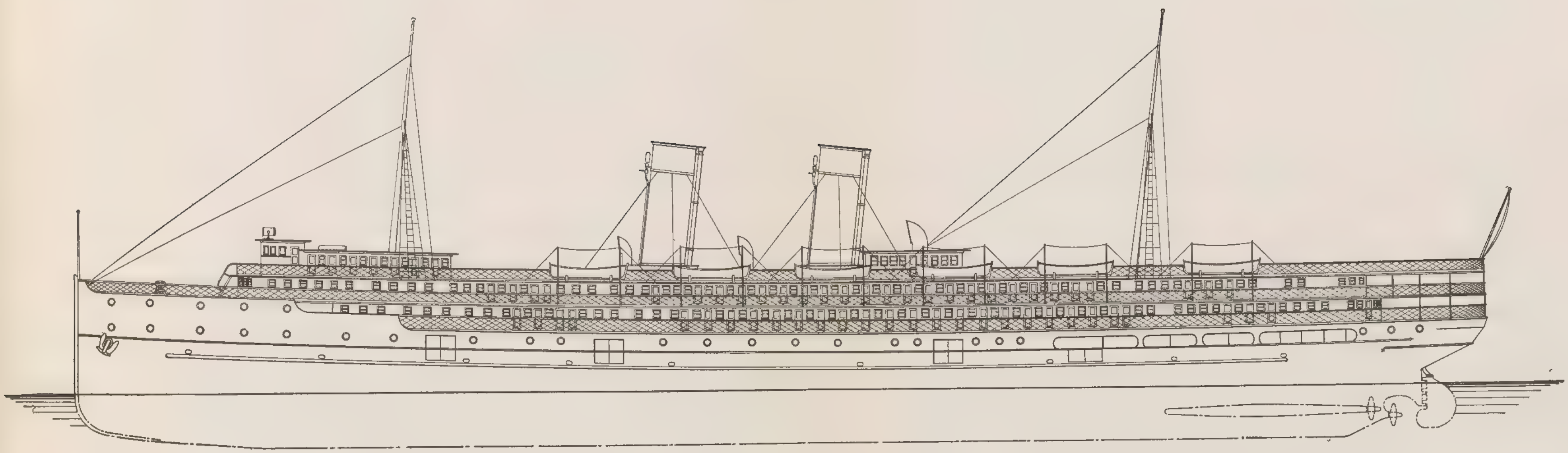
TURBINE STEAMER
BELFAST
BUILT FOR THE
EASTERN S.S.CO.
BY THE
BATH IRON WORKS
BATH, MAINE
1907



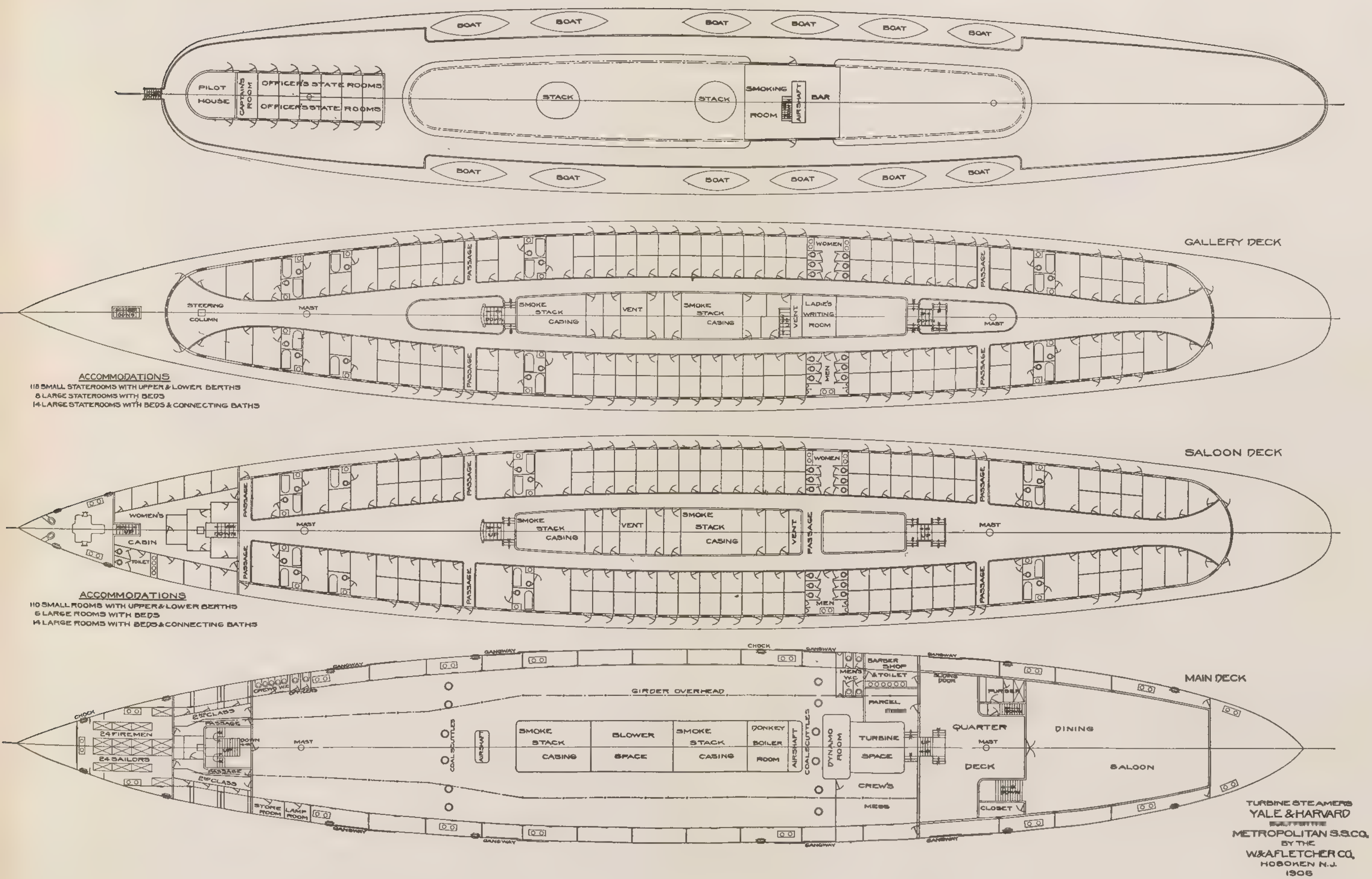
GALLERY DECK
SALOON DECK
MAIN DECK
LOWER DECK
ORLOP DECK
CAPTAIN'S ROOM
PASSAGE
PILOT HOUSE
BRASS BED
SPECIAL
ENGINE HATCH
BOILER
VENT TRUNK
FUNNEL
HATCH
MAST
RADIATOR
DOWN
UP
SOFT LIFE BOAT
MEN'S LAVATORY
WOMEN'S LAVATORY
CAPSTAN
STEERING GEAR
CARGO SPACE
CARGO
DINING SALOON
SOCIAL HALL
GALLEY
STEWARDS OFFICE
PURSER'S OFFICE
BAGGAGE ROOM
CREWS MESS
DYNAMO
UPPER ENGINE ROOM
BOILER CASING
GRATING
14 FIREMEN
CREWS W.C.
STEERING ENGINE ROOM
5-COAL PASSERS
GANGWAY
ENGINE
L.P. TURBINE
H.P. TURBINE
CONDENSER
ROOM
COAL BUNKER
WOMEN'S CABIN
80 BERTHS
OFFICER'S MESS
GALLEY AND PANTRY
MEAT BOX
ICE BOX
VEGETABLE LOCKER
PASTRY COOK
RANGE
TRIMMING TANK
MEN'S CABIN
120 BERTHS
LINEN CLOSET
LOCKER
BAR
FORECASTLE
28 PIPE BERTHS
RESERVE FEED TANK 4000 GAL
FRESH
WATER
TANKS
TOTAL CAPACITY 40 TONS
GLORY HOLD
30 PIPE BERTHS
10 PIPE BERTHS
CHAIN LOCKER
TURBINE STEAMER
BELFAST
BUILT FOR THE
EASTERN S.S.CO.
BY THE
BATH IRON WORKS
BATH, MAINE.
1907

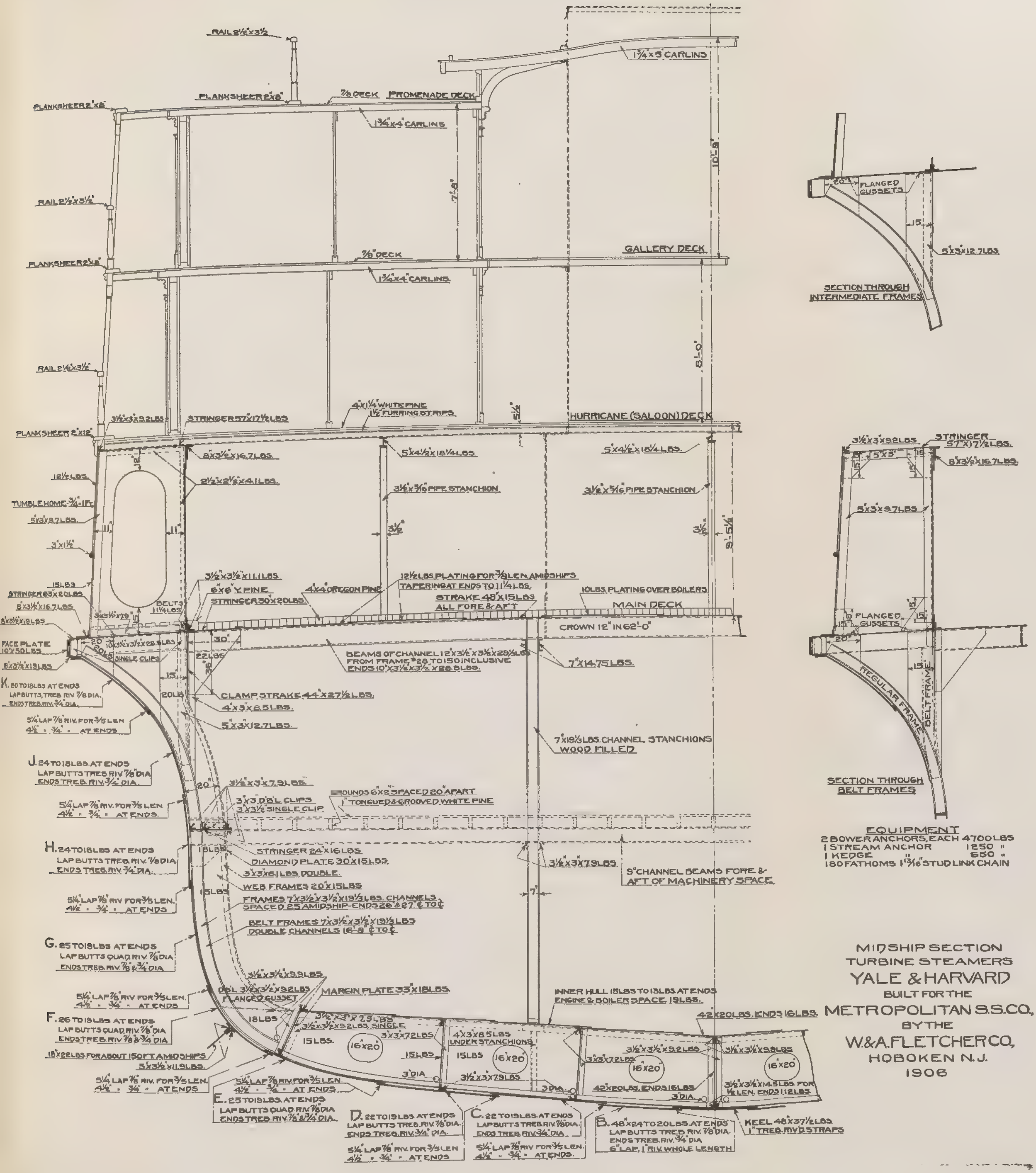


TURBINE STEAMER
BELFAST
BUILT FOR THE
EASTERN S.S.CO.
BY THE
BATH IRON WORKS
BATH, MAINE.
1907

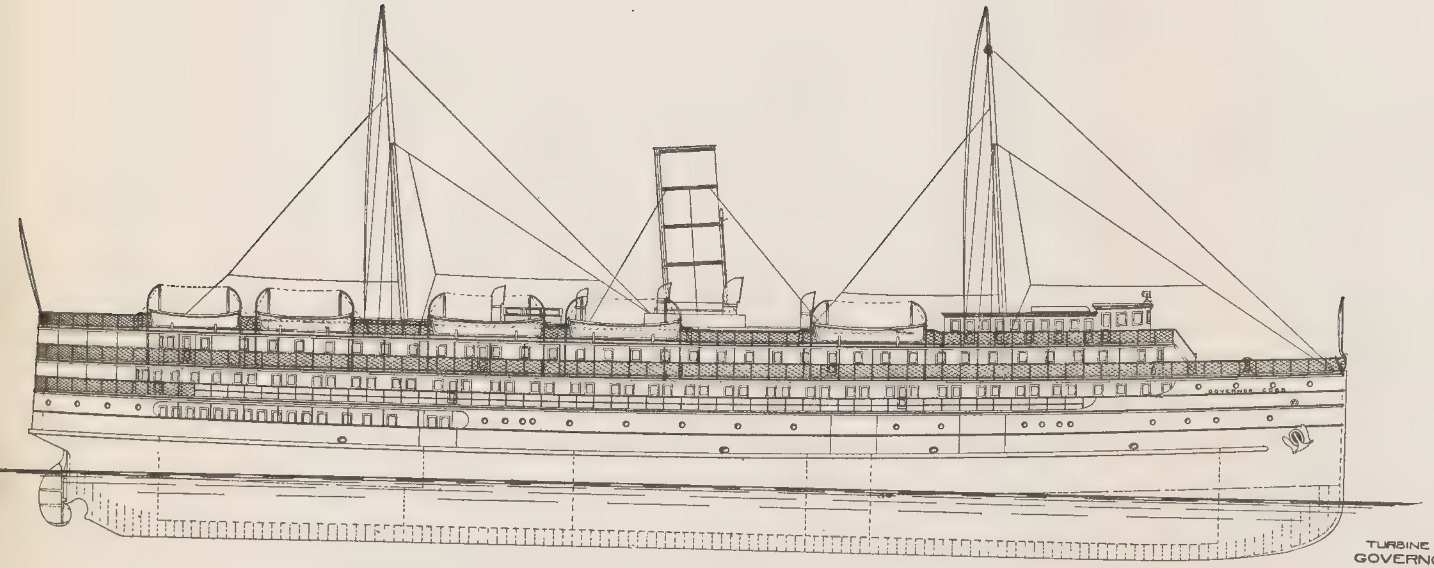


TURBINE STEAMERS
YALE & HARVARD

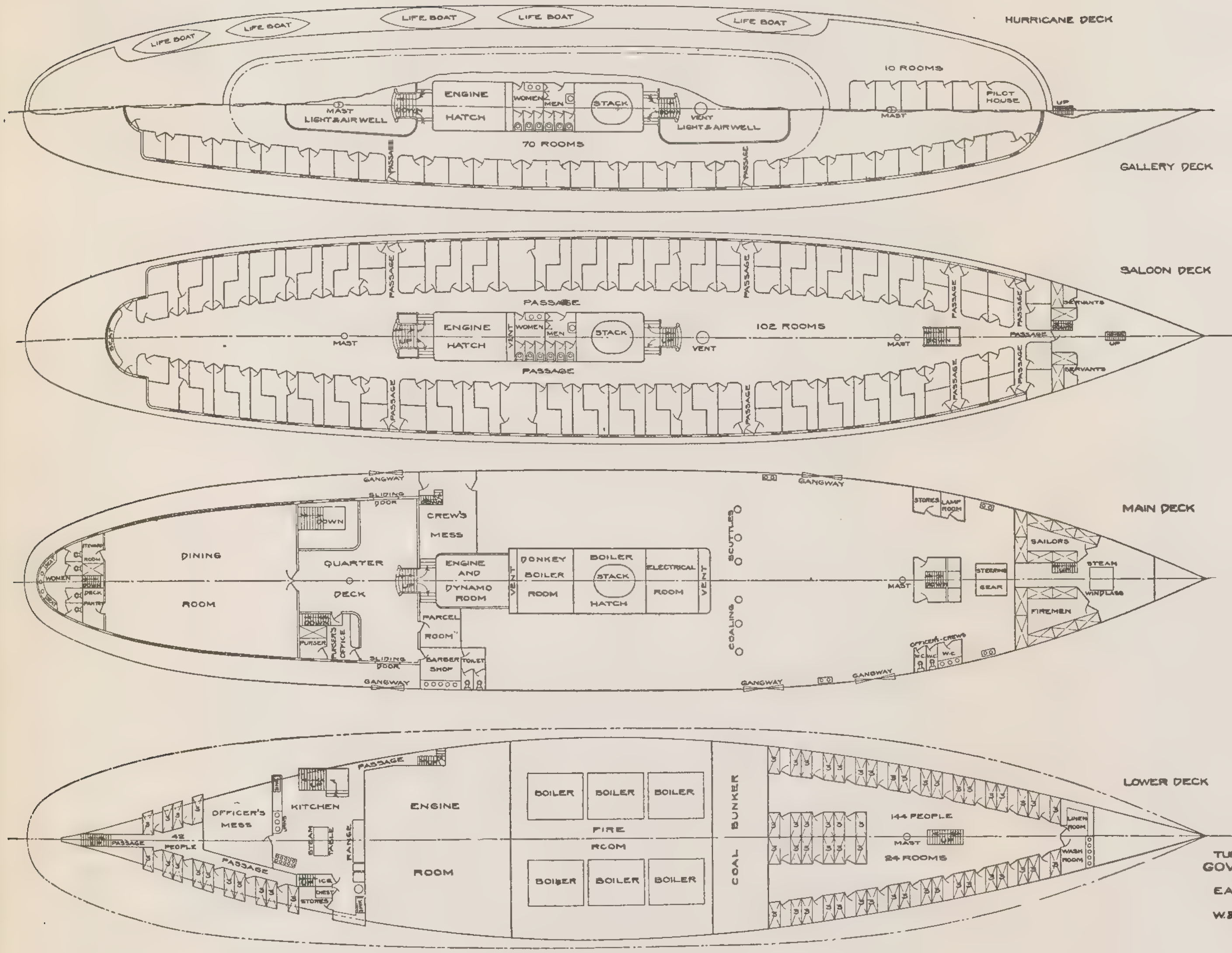

GALLERY DECK
ACCOMMODATIONS
118 SMALL STATEROOMS WITH UPPER & LOWER BERTHS
8 LARGE STATEROOMS WITH BEDS
14 LARGE STATEROOMS WITH BEDS & CONNECTING BATHS
SALOON DECK
ACCOMMODATIONS
110 SMALL ROOMS WITH UPPER & LOWER BERTHS
6 LARGE ROOMS WITH BEDS
14 LARGE ROOMS WITH BEDS & CONNECTING BATHS
MAIN DECK
TURBINE STEAMERS
YALE & HARVARD
METROPOLITAN S.S.CO.
BY THE
W.&A.FLETCHER CO.
HOBOKEN N.J.
1906



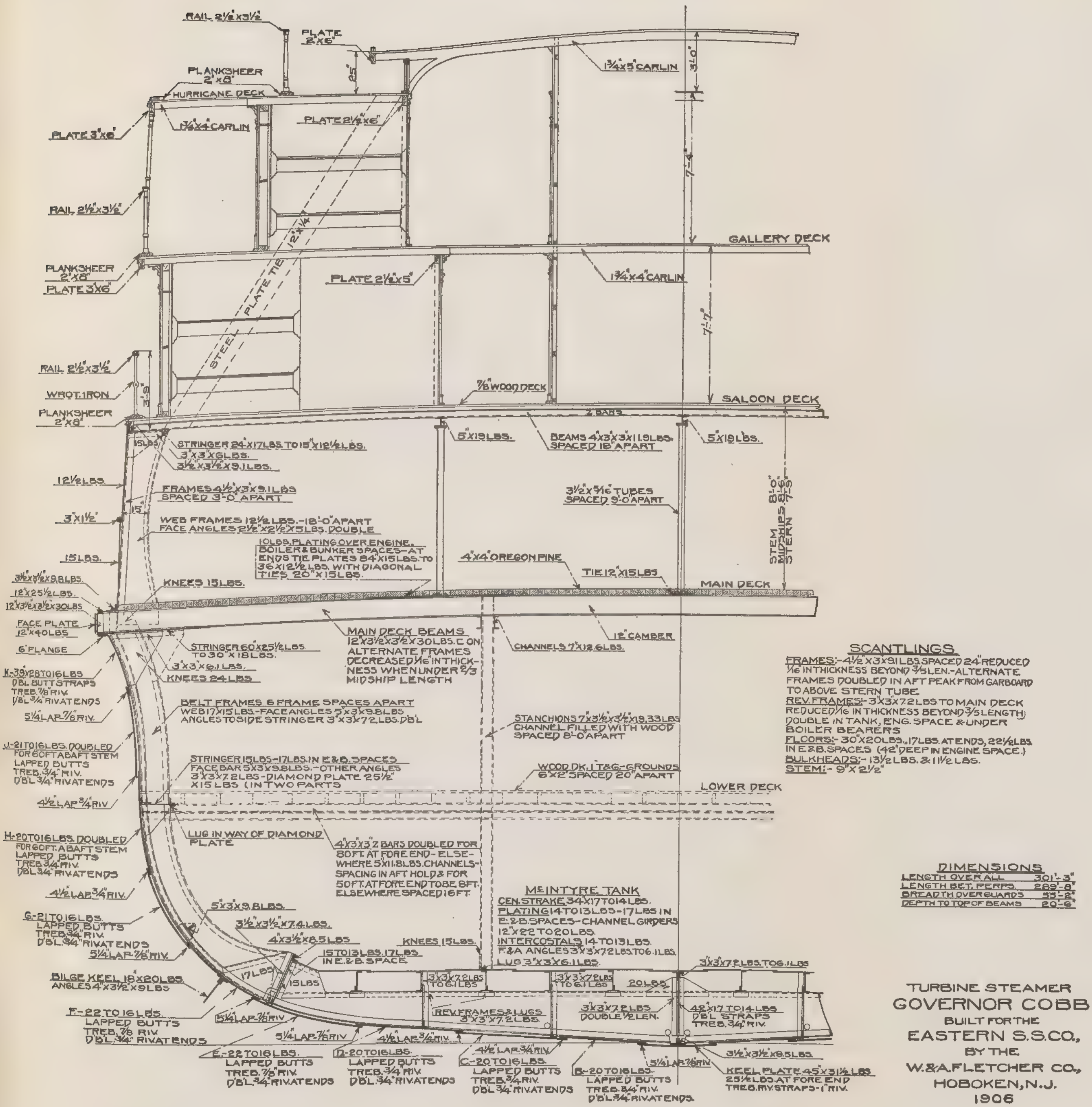
MIDSHIP SECTION
TURBINE STEAMERS
YALE & HARVARD
BUILT FOR THE
METROPOLITAN S.S.CO.
BY THE
W.&A. FLETCHER CO.
HOBOKEN N.J.
1906



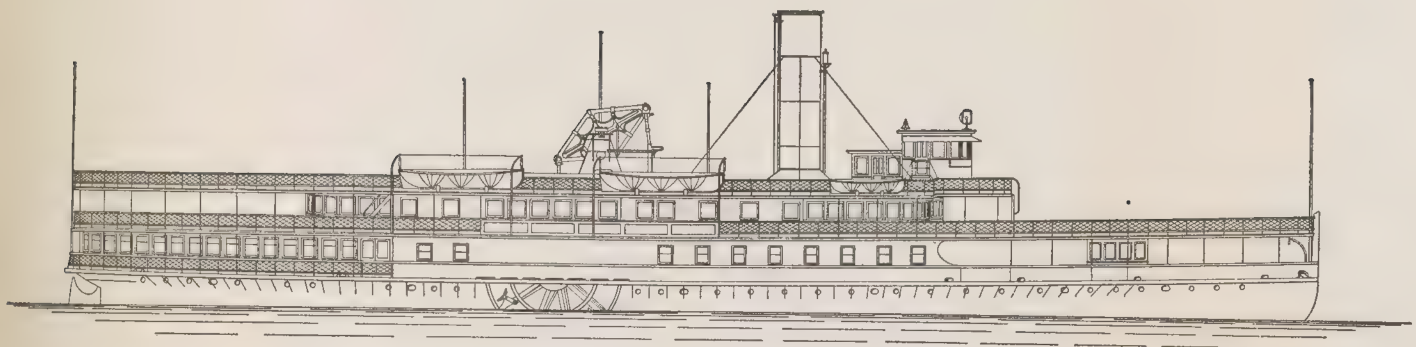
TURBINE STEAMER
GOVERNOR COBB
BUILT FOR THE
EASTERN S.S.CO.,
BY THE
W.&A.FLETCHER CO.,
HOBOKEN, N.J.
1906



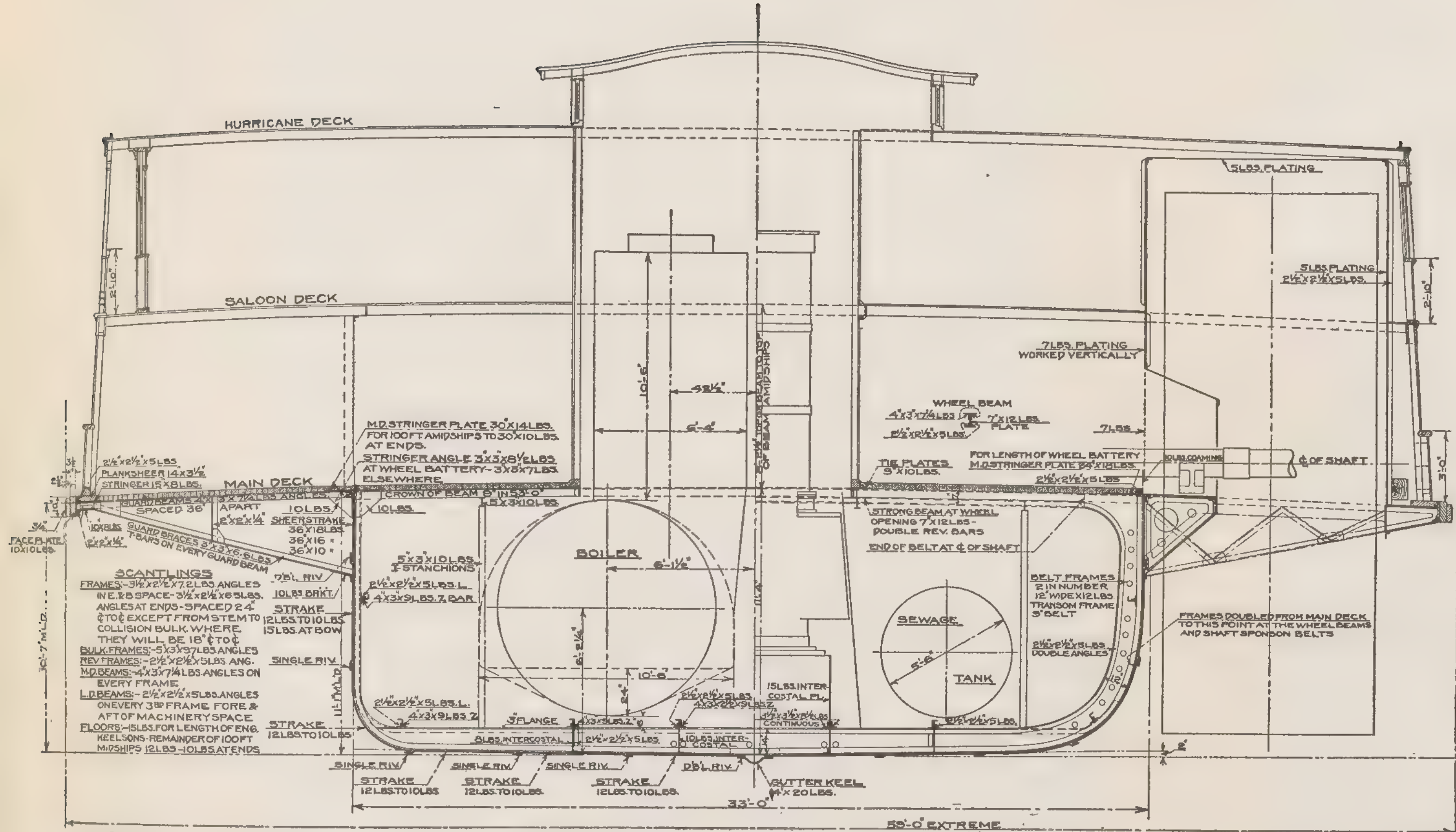
TURBINE STEAMER
GOVERNOR COBB
BUILT FOR THE
EASTERN S.S.CO.
BY THE
W.&A.FLETCHER CO.
HOBOKEN, N.J.
1906



RAIL 2½"x3½"
PLATE 2"x6"
PLANKSHEER 2"x8"
HURRICANE DECK
1¾x5" CARLIN
3'-0"
PLATE 3"x6"
1¾x4" CARLIN
PLATE 2¼"x6"
RAIL 2½"x3½"
7'-4"
STEEL PLATE TIE 12"x¼"
GALLERY DECK
PLANKSHEER 2"x8"
PLATE 3"x6"
PLATE 2½"x5"
1¾"x4" CARLIN
7'-7"
RAIL 2½"x3½"
WROT. IRON
3'-9"
⅞" WOOD DECK
SALOON DECK
PLANKSHEER 2"x8"
2 BARS
STRINGER 24"x17 LBS. TO 15"x12½ LBS.
3"x3"x6 LBS.
3½"x3½"x9.1 LBS.
5"x19 LBS.
BEAMS 4"x3"x3"x11.9 LBS. SPACED 18" APART
5"x19 LBS.
12½ LBS.
FRAMES 4½"x3"x9.1 LBS SPACED 3'-0" APART
3½"x5/16" TUBES SPACED 9'-0" APART
3"x1½"
WEB FRAMES 12½ LBS.-18'-0" APART
FACE ANGLES 2½"x2½"x5 LBS. DOUBLE
10 LBS. PLATING OVER ENGINE, BOILER & BUNKER SPACES-AT ENDS TIE PLATES 84"x15 LBS. TO 36"x12½ LBS. WITH DIAGONAL TIES 20"x15 LBS.
STEM 8'-0" MIDSHIPS 9'-6" STERN 7'-5"
15 LBS.
4"x4" OREGON PINE
TIE 12"x15 LBS.
3½"x3½"x9.8 LBS.
KNEES 15 LBS.
MAIN DECK
12"x25½ LBS.
12"x3½"x3½"x30 LBS.
FACE PLATE 12"x40 LBS.
MAIN DECK BEAMS 12"x3½"x3½"x30 LBS. C ON ALTERNATE FRAMES DECREASED 1/16" IN THICKNESS WHEN UNDER ⅔ MIDSHIP LENGTH
12" CAMBER
CHANNELS 7"x12.6 LBS.
6" FLANGE
STRINGER 60"x25½ LBS. TO 30"x18 LBS.
3"x3"x6.1 LBS.
KNEES 24 LBS.
K-39½ TO 16 LBS. DBL BUTT STRAPS TREB. ⅞ RIV. DBL ¾ RIVAT ENDS
5¼ LAP ⅞ RIV.
BELT FRAMES 6 FRAME SPACES APART
WEB 17"x15 LBS.-FACE ANGLES 5"x3"x9.8 LBS. ANGLES TO SIDE STRINGER 3"x3"x7.2 LBS. DBL
STANCHIONS 7"x3½"x3½"x19.33 LBS. CHANNEL FILLED WITH WOOD SPACED 8'-0" APART
J-21 TO 16 LBS. DOUBLED FOR 60 FT. ABAFT STEM LAPPED BUTTS TREB. ¾" RIV. DBL ¾" RIVAT ENDS
STRINGER 15 LBS.-17 LBS. IN E & B. SPACES
FACE BAR 5"x3"x9.8 LBS.-OTHER ANGLES 3"x3"x7.2 LBS.-DIAMOND PLATE 25½"x15 LBS. (IN TWO PARTS
WOOD DK. 1" T & G - GROUNDS 6"x2" SPACED 20" APART
LOWER DECK
4½" LAP ¾" RIV
H-20 TO 16 LBS. DOUBLED FOR 60 FT. ABAFT STEM LAPPED BUTTS TREB. ¾" RIV. DBL ¾" RIVAT ENDS
LUG IN WAY OF DIAMOND PLATE
4"x3"x3" Z BARS DOUBLED FOR 80 FT. AT FORE END-ELSEWHERE 5"x11.8 LBS. CHANNELS-SPACING IN AFT HOLD & FOR 50 FT. AT FORE END TO BE 8 FT. ELSEWHERE SPACED 16 FT.
4½" LAP ¾" RIV.
McINTYRE TANK
CEN. STRAKE 34"x17 TO 14 LBS.
PLATING 14 TO 13 LBS.-17 LBS IN E & B. SPACES-CHANNEL GIRDERS 12"x22 TO 20 LBS.
INTERCOSTALS 14 TO 13 LBS.
F. & A. ANGLES 3"x3"x7.2 LBS. TO 6.1 LBS.
LUG 3"x3"x6.1 LBS.
5"x3"x9.8 LBS.
G-21 TO 16 LBS. LAPPED BUTTS TREB. ¾" RIV. DBL ¾" RIVAT ENDS
3½"x3½"x7.4 LBS.
4"x3½"x8.5 LBS.
KNEES 15 LBS.
5¼ LAP ⅞ RIV.
15 TO 13 LBS. 17 LBS. IN E. & B. SPACE
17 LBS.
3"x3"x7.2 LBS. TO 6.1 LBS.
3"x3"x7.2 LBS. TO 6.1 LBS.
3"x3"x7.2 LBS. TO 6.1 LBS.
20 LBS.
BILGE KEEL 18"x20 LBS. ANGLES 4"x3½"x9 LBS.
15 LBS.
REV. FRAMES & LUGS 3"x3"x7.2 LBS.
3"x3"x7.2 LBS. DOUBLE ½ LEN.
42"x17 TO 14 LBS. DBL STRAPS TREB. ¾" RIV.
F-22 TO 16 LBS. LAPPED BUTTS TREB. ⅞ RIV. DBL ¾" RIVAT ENDS
5¼ LAP ⅞ RIV
5¼ LAP ⅞ RIV
4½ LAP ¾ RIV
4½ LAP ¾ RIV
E-22 TO 16 LBS. LAPPED BUTTS TREB. ⅞ RIV. DBL ¾" RIVAT ENDS
D-20 TO 16 LBS. LAPPED BUTTS TREB. ¾ RIV. DBL ¾" RIVAT ENDS
C-20 TO 16 LBS. LAPPED BUTTS TREB. ¾ RIV. DBL ¾ RIVAT ENDS
B-20 TO 16 LBS. LAPPED BUTTS TREB. ¾ RIV. DBL ¾ RIVAT ENDS
5¼ LAP ⅞ RIV.
3½"x3½"x8.5 LBS.
KEEL PLATE 45"x31½ LBS. 25½ LBS. AT FORE END TREB. RIV. STRAPS-1" RIV.
SCANTLINGS
FRAMES:-4½"x3"x9.1 LBS. SPACED 24" REDUCED 1/16" IN THICKNESS BEYOND ⅗ LEN.-ALTERNATE FRAMES DOUBLED IN AFT PEAK FROM GARBOARD TO ABOVE STERN TUBE
REV. FRAMES:-3"x3"x7.2 LBS TO MAIN DECK REDUCED 1/16" IN THICKNESS BEYOND ⅗ LENGTH, DOUBLE IN TANK, ENG. SPACE & UNDER BOILER BEARERS
FLOORS:-30"x20 LBS., 17 LBS. AT ENDS, 22½ LBS. IN E. & B. SPACES (42" DEEP IN ENGINE SPACE.)
BULKHEADS:-13½ LBS. & 11½ LBS.
STEM:-9"x2½"
DIMENSIONS
LENGTH OVER ALL 301'-3"
LENGTH BET. PERPS. 289'-8"
BREADTH OVER GUARDS 55'-2"
DEPTH TO TOP OF BEAMS 20'-6"
TURBINE STEAMER
GOVERNOR COBB
BUILT FOR THE
EASTERN S.S. CO.,
BY THE
W. & A. FLETCHER CO.,
HOBOKEN, N.J.
1906



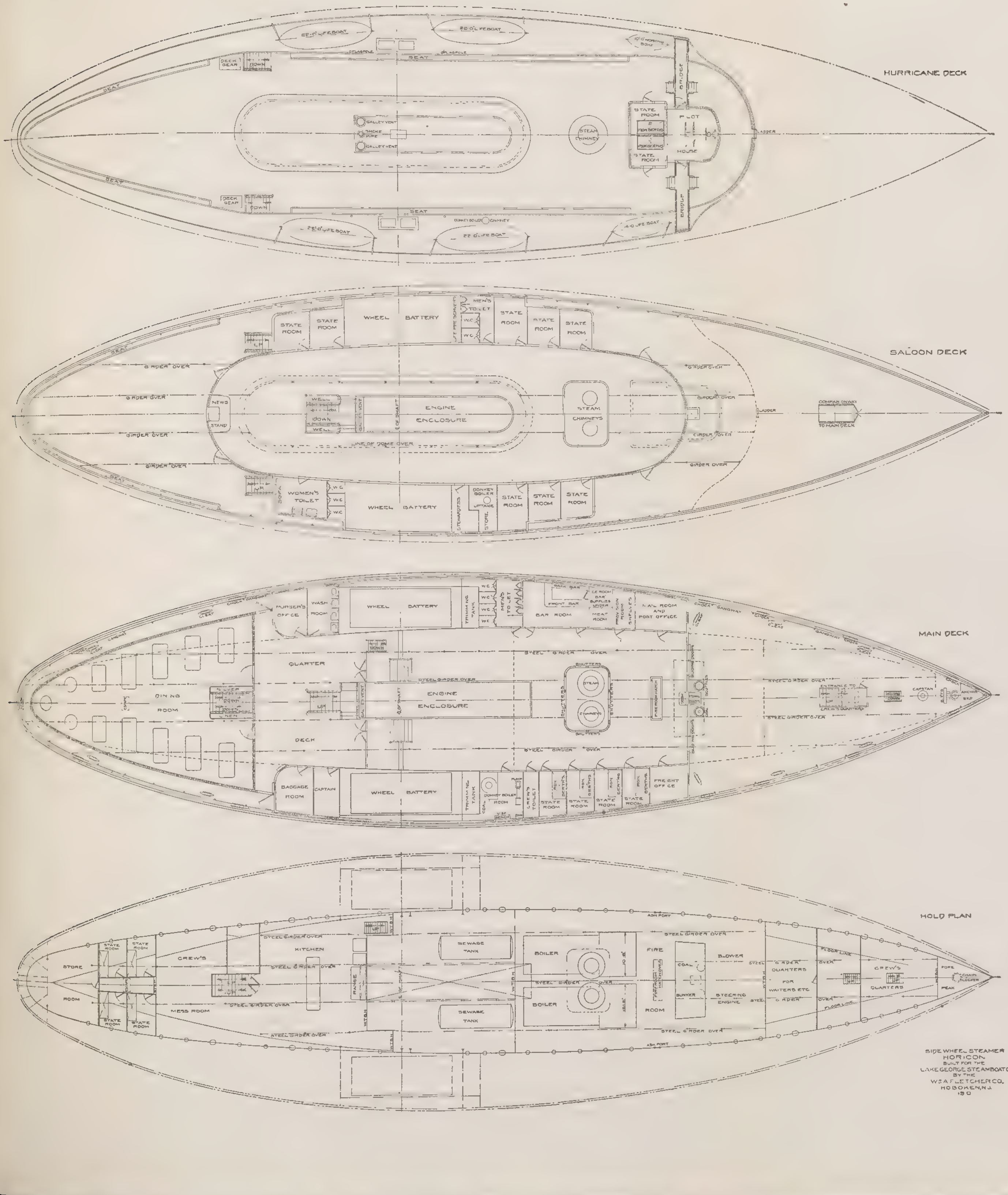
SIDE WHEEL STEAMER
"HORICON"
BUILT FOR THE
LAKE GEORGE STEAMBOAT CO.
BY THE
W.&A. FLETCHER CO.
HOBOKEN, N.J.
1910
J.W. MILLARD & BRO.
NAVAL ARCHITECTS

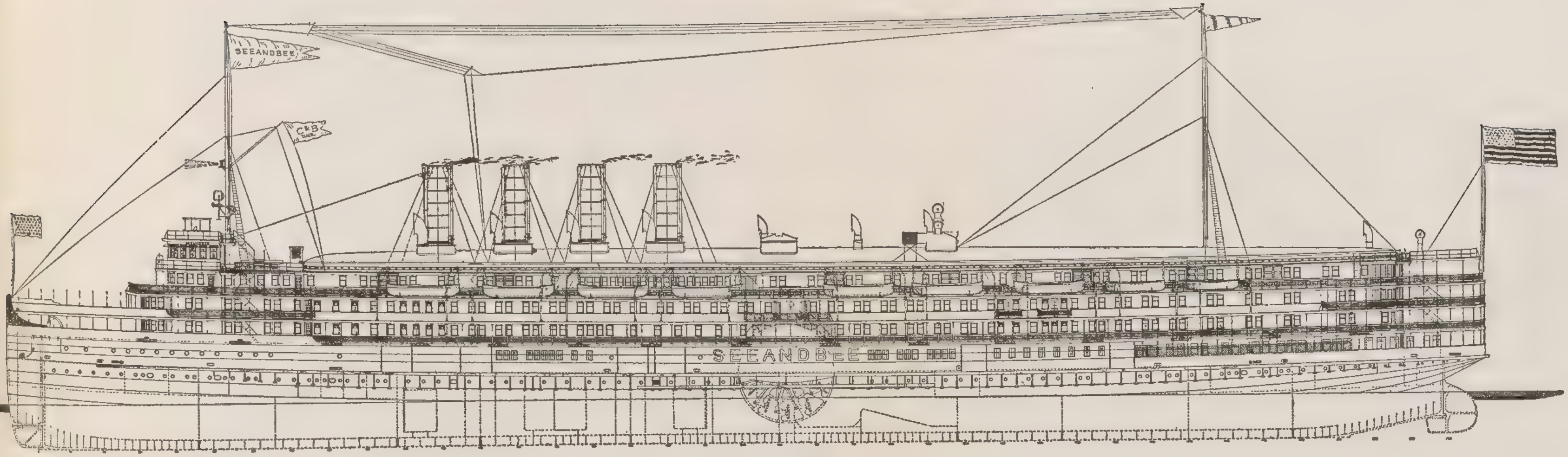


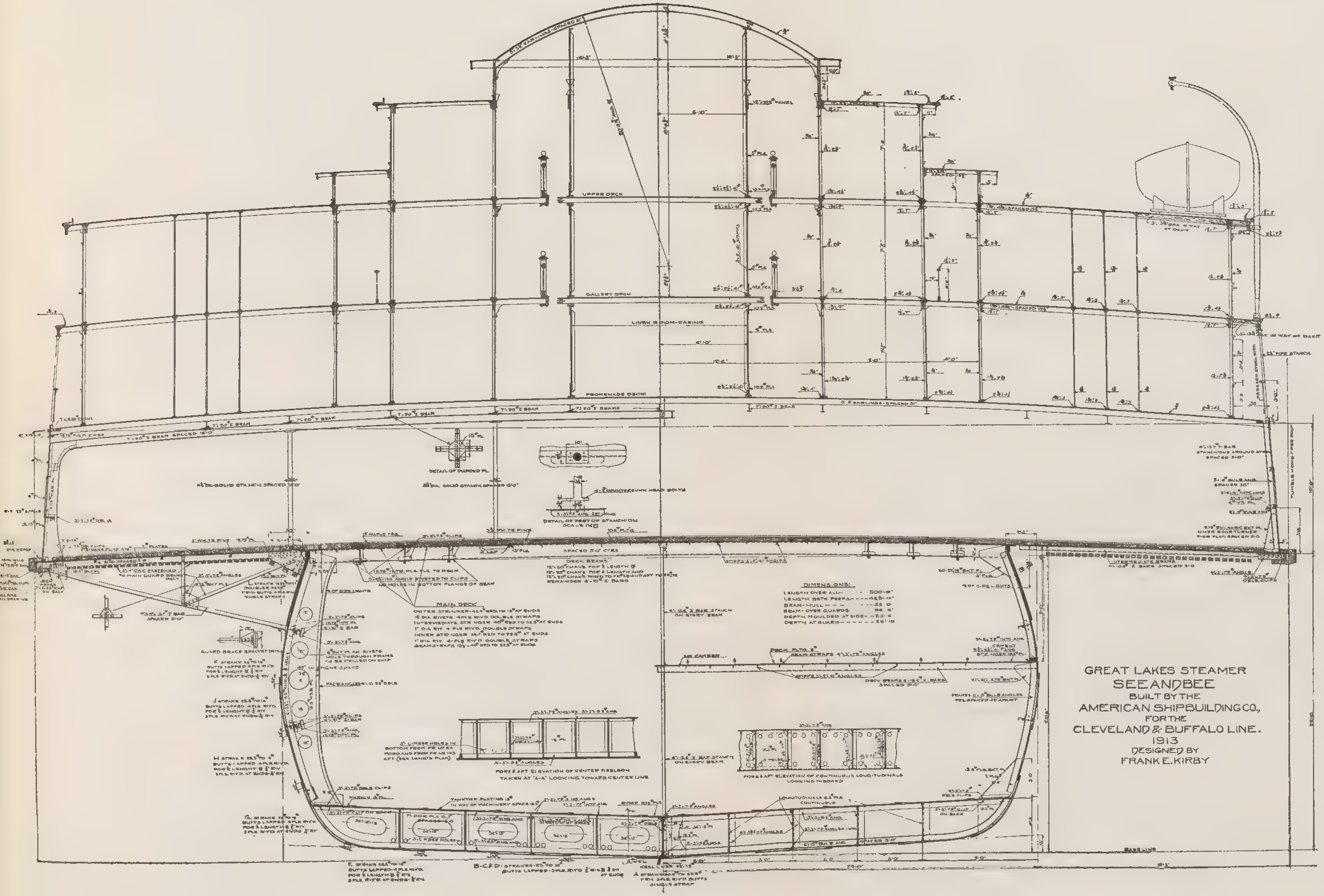
MIDSHIP SECTION **SECTION THRO' ℄ OF SHAFT**

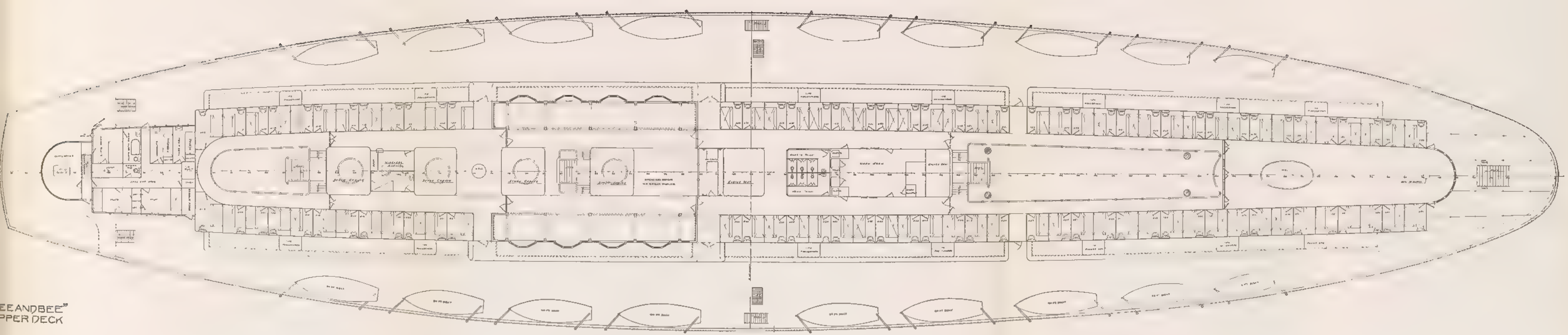
GENERAL DIMENSIONS	
LENGTH OVER ALL	230'-6"
LENGTH OVER STEEL HULL	226'-0"
LENGTH BET. PERPS.	220'-0"
BREADTH OF HULL	33'-0"
BREADTH EXTREME	59'-0"
DEPTH AT CENTRE LINE	11'-4"
DEPTH AT HULL, MOULDED	11'-1"
DEPTH AT GUARD, MOULDED	10'-7"

SIDE WHEEL STEAMER
HORICON
BUILT FOR THE
LAKE GEORGE STEAMBOAT CO.
BY THE
W.&A. FLETCHER CO.,
HOBOKEN, N.J.
1910

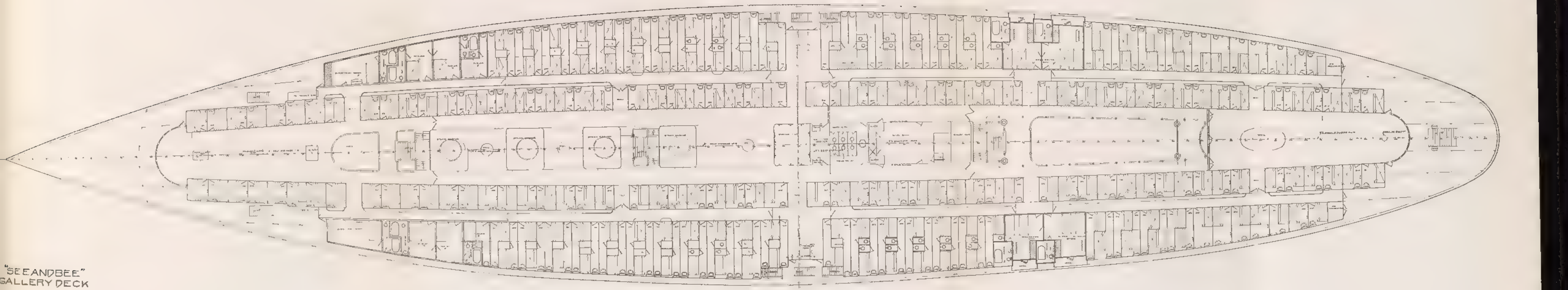

HURRICANE DECK
PILOT HOUSE
STEAM CHIMNEY
BRIDGE
SAL0ON DECK
SALOON DECK
WHEEL BATTERY
STATE ROOM
ENGINE ENCLOSURE
STEAM CHIMNEYS
WOMEN'S TOILET
MEN'S TOILET
MAIN DECK
PURSER'S OFFICE
WASH ROOM
BAR ROOM
MAIL ROOM AND POST OFFICE
QUARTER DECK
DINING ROOM
BAGGAGE ROOM
CAPTAIN
FREIGHT OFFICE
HOLD PLAN
STORE ROOM
CREW'S MESS ROOM
KITCHEN
SEWAGE TANK
BOILER
FIRE ROOM
BLOWER
STEERING ENGINE
QUARTERS FOR WAITERS ETC
CREW'S QUARTERS
FORE PEAK
CHAIN LOCKER
SIDE WHEEL STEAMER
HORICON
BUILT FOR THE
LAKE GEORGE STEAMBOAT CO.
BY THE
W. & A. FLETCHER CO.
HOBOKEN, N.J.
190


SEEANDBEE
C&B
SEEANDBEE

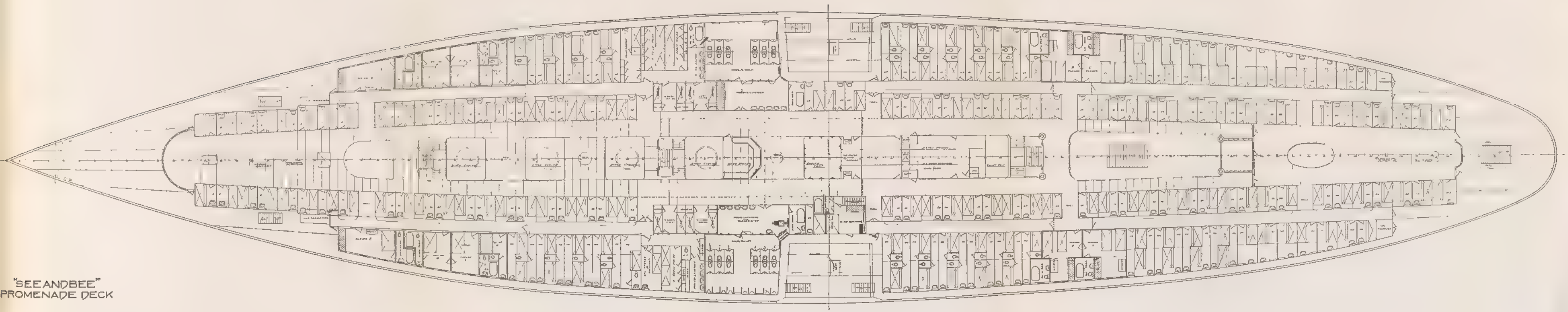

GREAT LAKES STEAMER
SEEANDBEE
BUILT BY THE
AMERICAN SHIPBUILDING CO.
FOR THE
CLEVELAND & BUFFALO LINE.
1913
DESIGNED BY
FRANK E. KIRBY



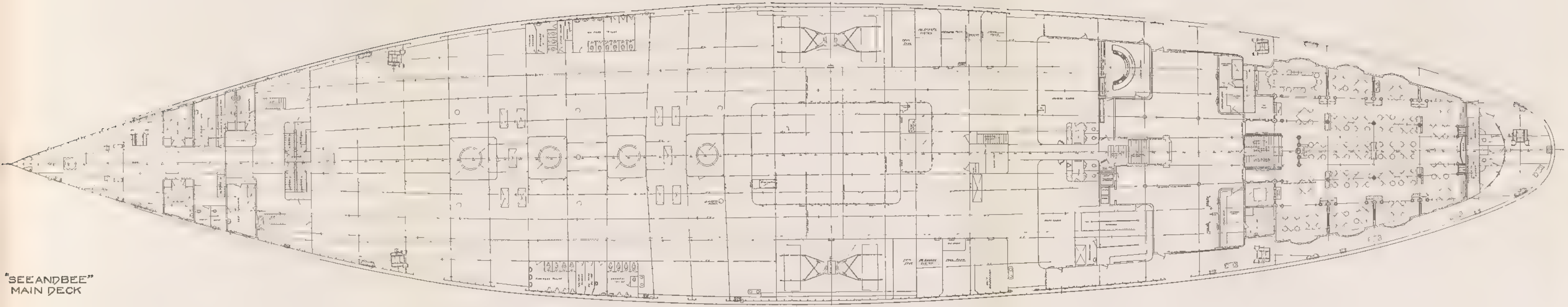
EEANDBEE"
PPER DECK



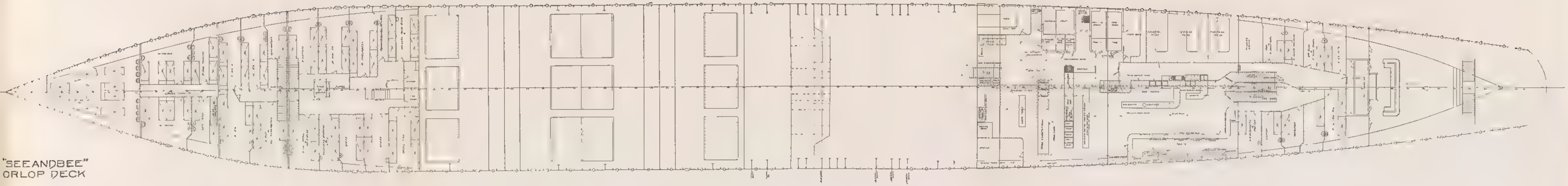
"SEEANDBEE"
GALLERY DECK



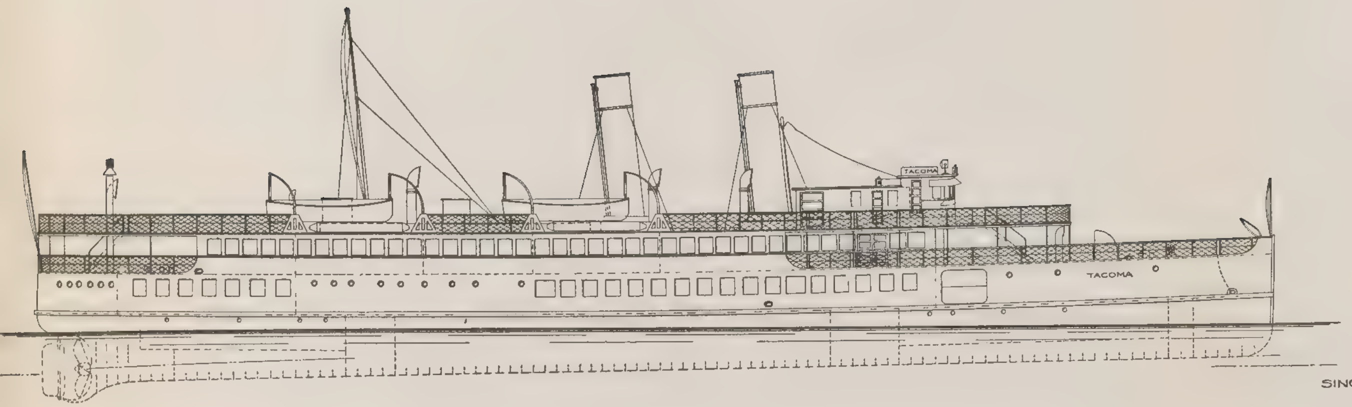
"SEEANDBEE"
PROMENADE DECK



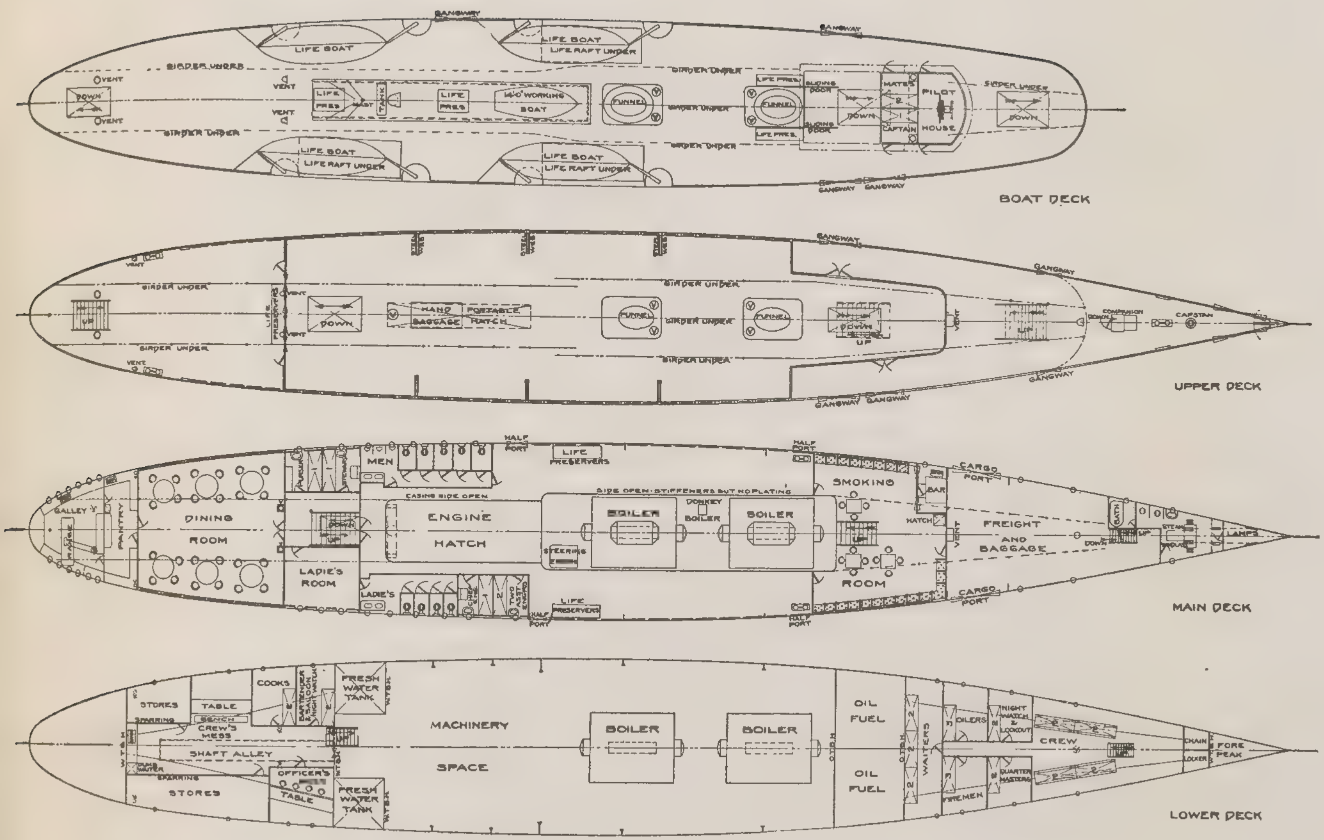
"SEEANDBEE"
MAIN DECK



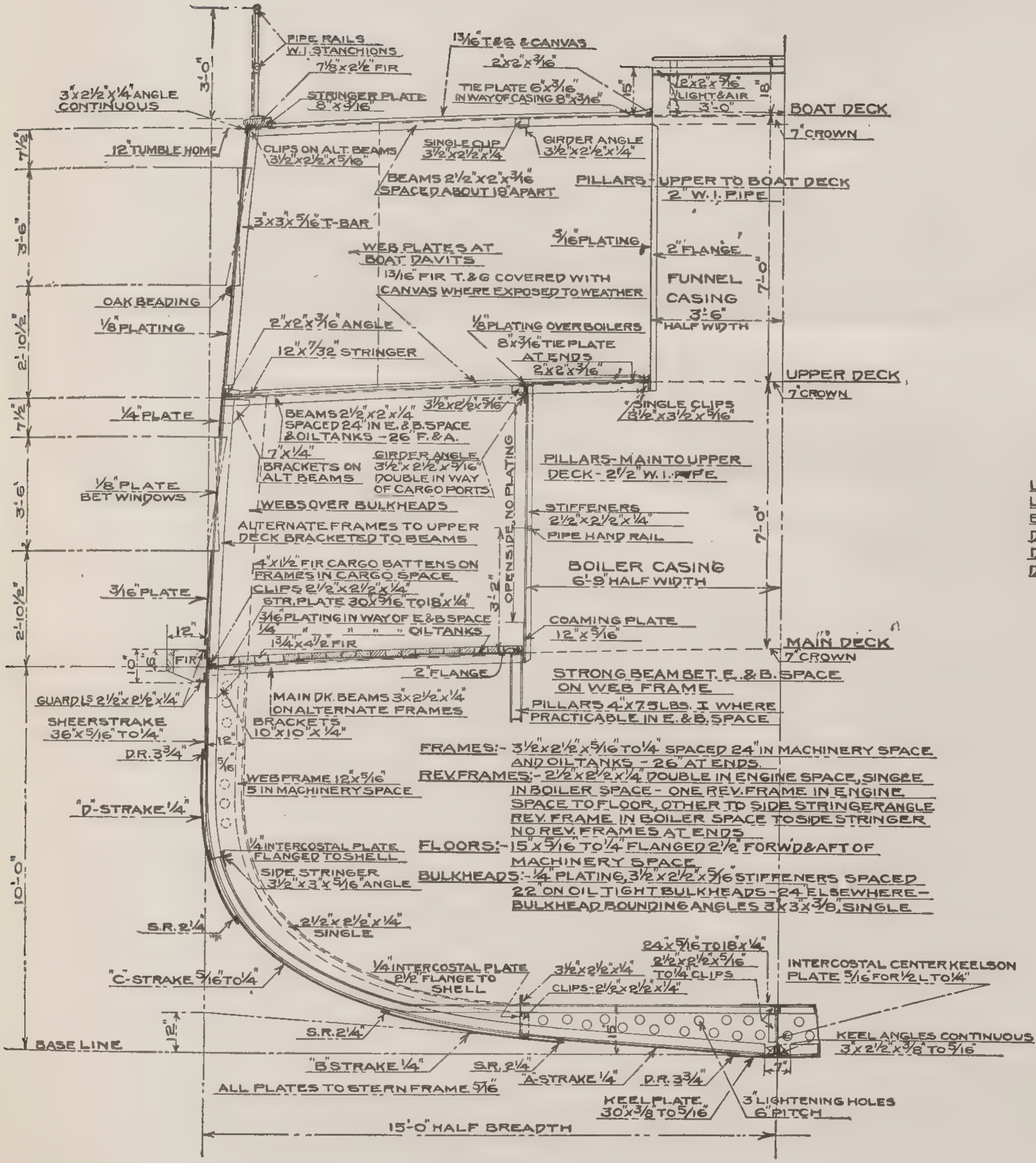
"SEEANDBEE"
ORLOP DECK



SINGLE SCREW STEAMER
TACOMA
BUILT FOR THE
PUGET SOUND NAVIGATION CO.
BY THE
SEATTLE CONSTRUCTION
AND
DRYDOCK CO.
SEATTLE, WASH.
1912



SINGLE SCREW STEAMER
TACOMA
BUILT FOR THE
PUGET SOUND NAVIGATION CO,
BY THE
SEATTLE CONSTRUCTION
AND
DRYDOCK CO.
SEATTLE, WASH.
1912



GENERAL DIMENSIONS

LENGTH OVER ALL	221'-0"
LENGTH BET. PERPS.	215'-0"
BREADTH MOULDED	30'-0"
DEPTH MOULDED	10'-0"
DEPTH M'L'D. TO UPPER DK.	17'-0"
DRAFT TO BOTTOM OF SHOE	12'-4"

SINGLE SCREW STEAMER
TACOMA
BUILT FOR THE
PUGET SOUND NAVIGATION CO.
BY THE
SEATTLE CONSTRUCTION
AND
DRYDOCK CO.
SEATTLE, WASH.
1912

inside of hulls, particularly in the wake of boiler and engine compartments. Deck sheathing of cement compositions; partitions of crews' quarters, when in hold, of light galvanized crimped steel; galley flooring, when in hold, of steel under the tiling; and the substitution of light steel construction, wherever practical, in place of wood in hold,—these are some of the many details of construction of the later boats.

MACHINERY.

On referring to the data sheet it will be found that the machinery of paddle steamers varies from the old, but very reliable, simple beam engine type to the more modern and efficient compound and three cylinder compound inclined and four cylinder compound double inclined engines, the last of the "Priscilla" type. The simple beam engine type has great durability, low initial cost and maintenance. The paddle wheels are of the feathering type with steel floats and the engines work in some cases at a piston speed of 650 ft. per minute. The boilers employed are of the old type of flue and return tubular boilers of 55 pounds per square inch working pressure, with long grates, high fire boxes, and simple forced draft both under and over grates. These features make a satisfactory equipment for short or special routes for a Lake, River and Harbor excursion boat.

Double poppet valves are used on simple beam engines, generally with fixed Stevens cut-off, and in some cases with adjustable Sickle's dash-pot cut-off, the length and necessities of the route determining. Double trip-shafts for raising main steam and exhaust valves are used on the larger engines, one trip-shaft for use by hand and the other for operating by steam, as may be desired when boat is maneuvering or approaching or leaving pier, when the main valve eccentric gear is disconnected.

The main valves of the inclined machinery of the paddle steamers of this paper are all of the double-beat poppet type, with the exception of those on the "Washington Irving", which are of the box balance slide type on the high-pressure, and double-ported slide on the low-pressure cylinders. The "Seeandbee" has double-beat poppet valves with Sickle's dash-pot cut-off on

the high-pressure cylinders and Corliss valves on the low-pressure cylinders. Stephenson link-gear is generally used, although the Walschaert gear is installed on the "Seeandbee" and a number of other paddle steamers, and has given excellent results. Piston valves have also been extensively used.

The main air-pumps are generally worked by the main engine. The "Washington Irving" has an independent air-pump. The condensers, main auxiliaries, feed-water heaters, filters, etc., are of the customary type. While jet condensers have, in the past, been mostly used on the Great Lakes (fresh water) in combination with water purifiers, in recent years surface condensers have been largely adopted.

Many of the paddle steamers are fitted with trim-tanks placed on the main guards, the tanks having a system of piping, quick-opening valves of large diameter, special turbine pumps, all operated from a bank of levers in main engine room. The main sanitary-pump systems are fitted with the usual governing and regulating valves, the discharge-circuit pipes at the pump having removable strainers. Wrecking-pump suctions to main water-tight compartments of the larger steamers are fitted with foot-valves and strainers and have a charging connection to pumps.

Boilers of the Scotch type are generally used for the inclined engines, with working pressure from 130 to 180 pounds per square inch. Where these boilers are used, on the latest-built paddle steamers of the larger size, they have been fitted with Howden's system of forced draft—for anthracite coal in the case of the "Washington Irving" and for bituminous coal on the "Seeandbee".

The machinery equipment of the screw boats shown varies from the usual triple-expansion engine to the Parsons marine-turbine type, all of which types are familiar to the members of this Congress. Comparatively few turbine steamers have been built in this country for the type of steamers embraced in the title of this paper.

While boilers of the Scotch type are most generally used for the screw steamers, water-tube boilers have been fitted to a number of steamers and with excellent results. Superheated steam has not as yet been extensively used on steamers of these types.

Oil fuel is not generally used, at present, on the river, lake, bay and sound steamers in the eastern part of the United States, because of the present high price of fuel oil and the difficulty of obtaining a ready supply; but on the Pacific Coast oil fuel is now extensively and most efficiently used and is a cheaper fuel than coal for that section of the country.

Superstructures.

On the later steamers, while the construction of the superstructures is largely of wood, steel girders and pipe stanchions are almost universally used. Engine and boiler enclosures and ventilating shafts up through the various decks are of steel construction. Deck houses in freight spaces are of steel, and it can be generally stated that in the larger modern boats, light steel construction or wood covered with galvanized iron is largely used wherever there is a possibility of fire in the motive-power, crews', emigrant, freight and galley departments. In a number of boats where the steel boiler and machinery enclosures, galley ventilators and heat uptakes are faced with wood on cabin side, the steel enclosures are lined with non-conducting materials. The steamer "Commonwealth", referred to previously, has two fire bulkheads up through the superstructure on the various decks, dividing the boat into three sections or fire zones. The "Seeandbee" has several fire screens installed for a similar purpose.

Composite board, wall-board, Agasote, Nevasplit and various substitutes for wood—materials with slow-burning properties—are extensively used for panels for cabins, doors, partitions, dome ceilings, wainscoting, etc. Paneled partitions, rather than tongue and groove materials, are used between staterooms on many of the steamers, thus reducing the lodging places for vermin. The exterior facing of wood deck-houses on the various decks is exceedingly plain and, where paneled, they are practically free of mouldings. In many cases, sidings are smooth sheathed and canvassed, producing a plain surface which may be easily painted and cleaned.

There has been within the writer's recollection but one passenger and freight all-steel superstructure and so-called fireproof steamer built in the United States, and members are referred to the Transactions of the Society of Naval Architects

and Marine Engineers, Vol. 14, 1906, for a full description. The steamer has not been duplicated as yet. There have been built in recent years, however, three or four single-deck ferry-boats with all-steel superstructures that have given good results. But the superstructure on boats of this class (with but two large straightway cabins and two team- and motor-ways), is of an extremely simple construction, for the amount of superstructure is small, and neither the weight, the heat-absorbing qualities in warm weather, nor the additional cost of a steel superstructure on a boat of this character would compare with an all-steel superstructure on a many-decked excursion or stateroom steamer; and even though the additional weight and higher initial cost were not considered, the writer believes that the expansion and contraction of the necessarily light-steel and many-jointed sections and members, due to atmospheric changes, the loosening of joints due to vibration when boat is under way, and also the difficulty of scaling and painting, would in the aggregate increase the cost of maintenance and repairs, particularly in case of damage by collision. The subject of an all-steel superstructure for passenger boats is commented on, for it has been discussed very often in recent years, and while all owners, naval architects and builders should do everything possible to prevent loss of life by fire, the practical side must be considered.

In recent years a greater number of parlors, suites and feature rooms have been built, as well as a greater number of and wider stairways, companionways, etc.; the interior design and decoration of the cabins and saloons of our large steamers are largely patterned after dwellings or hotels. More attention has been given to the modernizing and refining of the heating, ventilation, plumbing and sanitation. Single- and double-decked iron bedsteads are extensively used, instead of the wood-front built-in berths. Private baths and toilet rooms are more generally demanded by the traveling public. Telephones are general.

The equipment for extinguishing fires is more complete on the later steamers than on the older ones. Sprinkler systems, while not generally used at present, are installed in various ways. In the writer's opinion, a system divided into a number of separate and distinct circuits with a corresponding number

of thermostatic circuits in iron conduits, connected with various annunciators in the main saloon and main pump room, indicating circuit and location of fire, and having a special sprinkler pump under pressure at all times, together with a first-class fire alarm system, makes a more practical, safe and efficient system for a steamer, than either the ordinary automatic wet-pipe or dry-pipe system. In addition to a sprinkler system, an independent four-pipe fire system, with a large number of fire valves, should be installed, particularly on large stateroom steamers. On the excursion type of steamer, the better and larger class of boats have four independent fire-pipe systems leading directly from the main pumps; such a system on a steamer like the "Washington Irving" has about forty fire plugs.

The equipment of the modern steamer with its fire systems, as above outlined, together with a greater number of fire extinguishers, watchmen's clocks, regular crew drills, electric-light wiring in iron conduits, extra dynamos, two independent hand and steam steering-gear leads, and the equipment and bulkhead and hull construction requirements of the U. S. Steamboat Inspection Rules, all have made possible the present high general safety of transportation on the River, Lake, Bay and Sound Steamers, as has been shown by the U. S. Government records in the very small percentage of lives lost to the great number carried.

Careful designing by the naval architects and marine engineers for the service requirements, complete equipment, able and conscientious Government inspection and efficient and well disciplined crews are absolutely necessary to maintain the safety of water transportation.

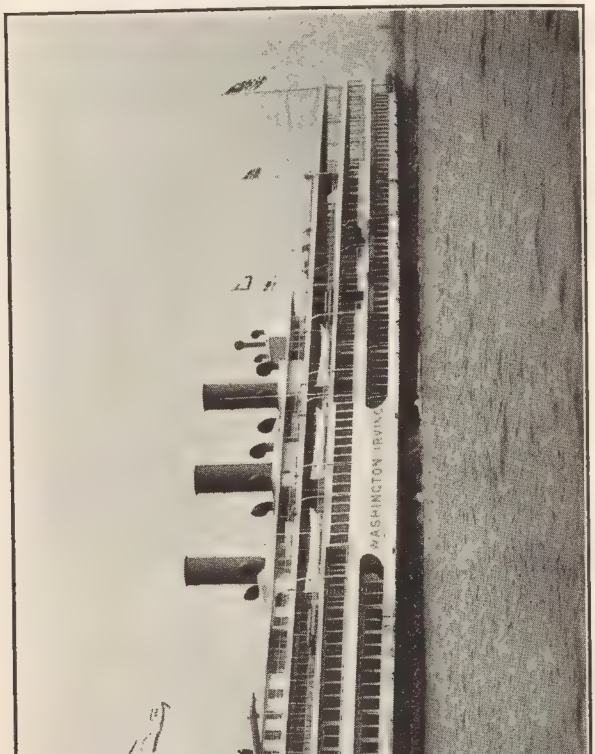


Fig. 1. Paddle Steamer "Washington Irving".

Fig. 2. Paddle Steamer ''Berkshire''.

Fig. 3. Screw Steamer "Benjamin B. Odell".

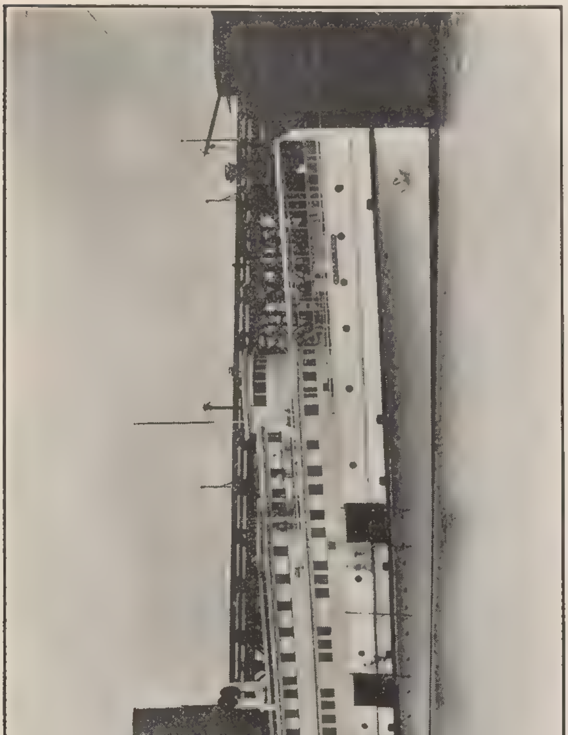


Fig. 4. Screw Steamer "Northland".

Fig. 5. Twin Screw Steamer ''Maryland''.

Fig. 6. Paddle Steamer "Rose Standish".

Fig. 7. Paddle Steamer ''Priscilla''.

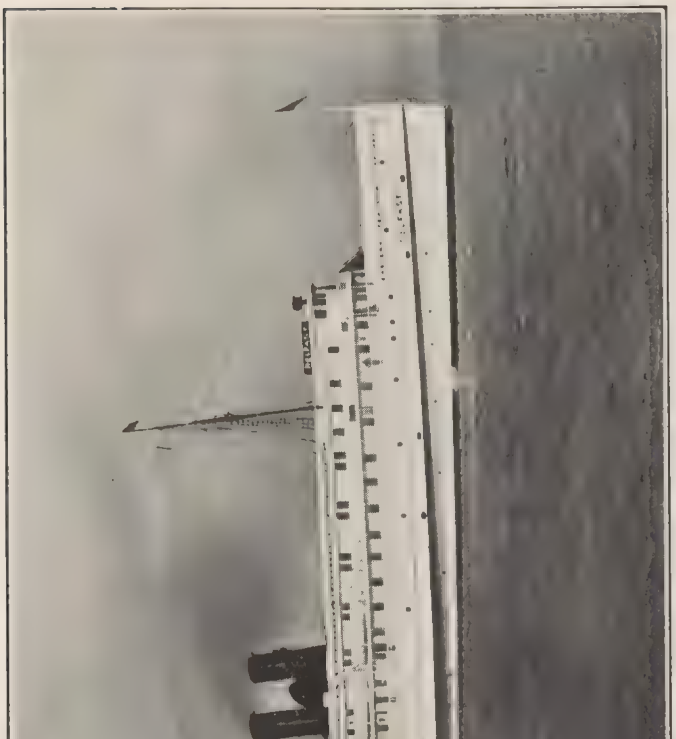


Fig. 8. Triple Screw Steamer "Belfast".

Fig. 9. Triple Screw Steamer "Yale".

Fig. 10. Triple Screw Steamer "Governor Cobb".

Fig. 11. Paddle Steamer ''Horicon''.

Fig. 12. Paddle Steamer ''Seeandbee''.

Fig. 13. Screw Steamer ''Tacoma''.

Paper No. 201

SPECIAL TYPES OF CARGO STEAMERS FOR THE UNITED STATES COAST-TO-COAST TRADE THROUGH THE PANAMA CANAL.

By

GEORGE W. DICKIE
Vice-Pres. Am. Soc. M. E., Vice-Pres. S. N. A. & M. E.
San Francisco, Calif., U. S. A.

The size of a steam or motor ship is determined by the length of the voyage and her proportions are governed by its nature, but her type is definitely decided by the character of her cargo.

There is a predominance of lumber in the East-bound cargoes to be handled, and at some seasons a demand for suitable transport for fresh and dried fruits and wines. The West-bound cargoes are of a general character requiring great hold space with intermediate decks to support the freight. The type of vessel demanded by part of the East-bound freight and all of the West-bound is not suitable for the economical transportation of lumber, which is the predominating part of the East-bound.

To comply with the requirements of these several diverse traffics, demands a compromise type possessing the useful qualities of the "shelter-decker" for general cargoes and the economies of the lumber steamer, with its deck load and unobstructed holds. It would be very difficult, in the light of our present knowledge at least, to improve on the freighters of the American Hawaiian Steamship Company for the general freight business for which they were designed. Of our latest lumber-carrying vessels, it may be said that for the special purpose for which they were built, they are very economical and constitute a highly developed type. It is a desire to combine the good qualities of both these types in one compromise design, retaining as much as possible of the good of both and

sacrificing the special functions of neither, that has led me into this attempt to combine or fuse these contending and contradictory elements of design.

In addition to the special requirements of the lumber trade, there are those necessary for the safe carriage of fresh fruits and vegetables. These must be carried in insulated compartments ventilated and cooled by blowing in washed air at a temperature sufficiently low to keep the temperature of the rooms at about 40 degrees. The carriage of wine in casks is wasteful of space and necessitates the return of empties; the possibility of carrying considerable amounts of wine in bulk should be a desideratum in designing a ship for the Canal Trade.

The inadaptability of the pure lumber steamer for carrying general cargo is caused by lack of 'tween-decks spaces and lack of stowage space. Without the deck load to give them height of side, they suffer seriously from lack of freeboard. On a long sea voyage the return half of which would be in a loaded condition without deck load, our present type of lumber vessel would be continually liable to damage from shipping seas which a vessel with adequate freeboard would ride over without difficulty. Since when loaded, these vessels are down practically to the weather deck, they may be said to be only the bottoms of vessels with certain erections built on, and the deck load furnishes the top side and most of the surplus buoyancy. Their draft is limited by the depth of water at the lumber ports; for the purpose of carrying lumber, the entire draft is made available for depth of vessel by loading them "decks to" with lumber piled high above them, and this condition, which gives them their efficiency as lumber carriers, makes them unsuitable for the business of general freight carriers.

Considerations of economy of operation make large vessels necessary on long runs, but a large vessel with a comparatively light draft is not economical and it becomes necessary to assume that it will be feasible to take on a considerable load of lumber in part of the interior and on part of the deck, bringing the vessel down to the available depth of water at her lumber port, and then proceeding to some other port and taking on a further loading of general cargo to bring her down to a draft propor-

tional to her size. This implies that the hatches to the interior be left entirely free of any deck load or other hindrance, so that the second loading may be proceeded with without disturbing the first.

From the foregoing considerations it is clear that we must combine the advantages of a 'tween decks in the hold and a shelter deck, giving buoyancy and stowage but adding to the gross tonnage and cost, with the advantage of a free deck for lumber easily loaded and not included in the gross tonnage. By making the lumber type of vessel deeper in the hold, adding a middle deck, carrying the hatches up through the deck load by making a continuous trunk for them, making in effect a partial shelter deck type, it is possible to accomplish some of the objects desired. Since it is inadvisable to stow lumber and general freight in the same hold and to get an even distribution of the first lading, it becomes necessary to put fore and aft bulkheads through the holds, forming a large deep central hold and two wing holds between each pair of athwartships bulkheads, the upper part of the central hold forming the trunk for its hatches and the hatches for the wing holds being trunked through the deck load alongside the central trunk.

The type produced by this subdivision is a modification of the turret or trunk steamer. The necessity of carrying either lumber or general freight economically can be successfully accomplished by this type. An outline design along these lines is shown on Plates 1 and 2.

It would take much time and study of the trade under consideration to figure the probably most efficient capacity for this ship. She must be of considerable size to be economical, and the size of the three hatches in the breadth makes a great beam imperative. For purposes of illustration, dimensions have been assumed which will give a vessel, suitable and economical, but possibly not the most suitable and economical.

Length between perpendiculars	420′ 0″
Breadth moulded	60′ 0″
Depth moulded to main deck	28′ 0″

On Plate 1 is shown the Profile Outboard, Top of Trunk, Poop, and Forecastle, Bridge House and Bridge, Main Deck, and an Outline Section.

On Plate 2 is shown a structural section.

These outlines show the vessel propelled with ordinary reciprocating engines supplied with steam by three Scotch marine boilers, the installation being intended for 3000-horsepower Diesel engines, or turbines with electric or gear reduction, might, with advantage, be used, for in that case the amount of fuel carried would be sufficient for a round voyage. The method of propulsion is no part of the present investigation, however, except in its bearing on the ultimate economy obtainable from the lessened consumption of oil fuel which would make it possible to take fuel at only one point—which point would be wherever it could be had cheapest.

Longitudinally, the cargo space is divided into four equal compartments, each 75 ft. 10 in. long; transversely, into three; and vertically, into two in the wings and three in the center part, making 28 separate cargo holds. The design contemplates that the middle compartments, including the trunk, will be loaded with lumber on the East-bound trip, except when the trunk is used for fresh fruit. The middle holds have hatches about 50 feet long and 14 feet wide, enabling lumber to be put into them with little or no hand labor. The method of handling will be described later. Each of the side holds has a hatch at the middle of its length about 15 feet long and 9 feet wide. Above the main deck, trunks are built up to the height of the central trunk, so that the deck load can be stowed and secured before the general cargo is taken aboard. Lumber up to 54 feet long can be stowed from wing hatch trunk to wing hatch trunk alongside the central trunk. Timbers of any length can be stowed outside the line of the wing hatch trunks.

The design contemplates that lumber will be carried in all the central compartments and the trunk, except when the latter is used for fruit. The amount of lumber that could be carried would be as follows:

Central holds and trunk	1,575,000 ft.
Deck load (8 ft. high)	800,000 "
Total	2,375,000 "

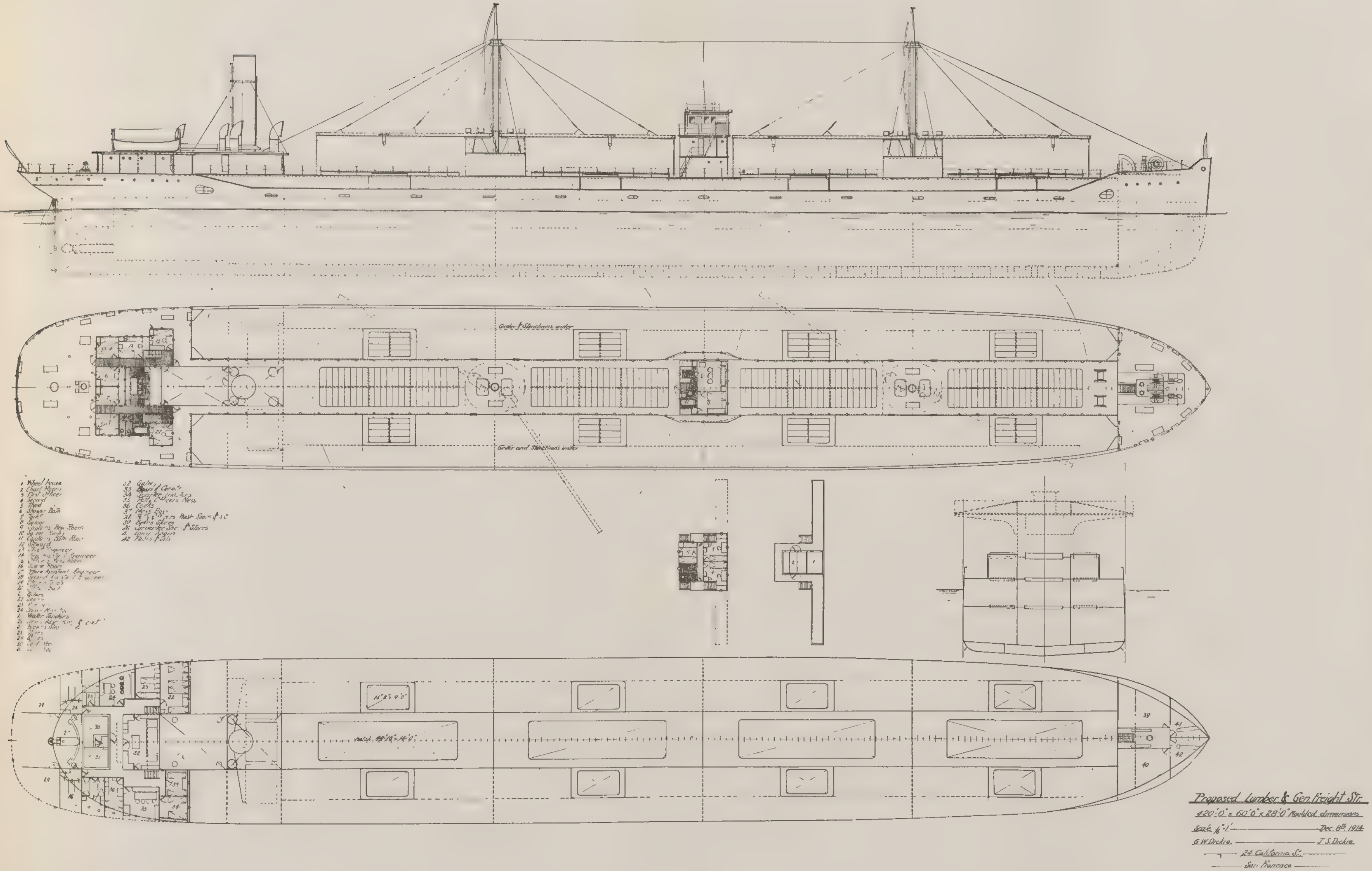
A somewhat higher deck load could undoubtedly be carried if desired, and the amount of lumber increased accordingly.

It is taken for granted that after discharging her West-bound freight at San Francisco and taking on fuel for her next round voyage, the vessel would proceed North to some lumber port and take on the lumber part of her cargo. On this account the central holds amidships would be fitted up as deep ballast tanks and would hold about 1600 tons. These holds could also be used for carrying wine in bulk when necessary. With bunkers full and deep tanks ballasted, there would be 2600 tons of dead weight, which would give a satisfactory condition for going north on this coast. Laden with 2,375,000 feet of lumber and complete supply of fuel and stores, her draft would be about 16½ feet, which would be perfectly safe in the lumber ports. Her lumber being aboard, she proceeds to the port at which she is to load general freight, which would be made up of various boxed, sacked, and bulk commodities and wine in barrels. For this she would have left 16 compartments, with an aggregate capacity of 232,000 cubic feet, or 5800 measurement tons @ 40 cubic feet. The lumber would weigh about 3562 tons and the measured cargo about 4000 tons, making the total weight of cargo 7562 tons. For the round voyage there would be about 1200 tons of fuel and 240 tons of food, stores, and supplies, making a total deadweight of 9002 tons. The weight of the ship, light, would be about 4138 tons, making the total load displacement 13,140 tons, which on a draft of 24 feet would give a block coefficient of 0.76—about the right fullness for a vessel of this type on long voyages.

Green fruit, when carried, would be properly stowed in the trunk compartments, which would be efficiently insulated by slab cork applied to the walls of the trunk between the stiffeners. A similar insulation would be made at the top and bottom between the beams. On each side, close down to the deck forming the floor, would be ducts for cold air, with properly arranged outlets, adjustable to suit conditions. The air would be filtered and passed through a cooling-box over nests of refrigerating pipes so as to keep the temperature of the fruit holds at or about 40 degrees. The proper amount of insulation and the extent of the refrigeration necessary would be modified by experience. The problem is simply that of the cooling of fruit cars in the transportation of green fruit by rail.

The double bottom would be constructed to perform two functions. The central part, for about fifteen feet each side of the center line and from the fore-peak bulkhead to the after boiler-room bulkhead, would carry the fuel oil. The double bottom would be of the ordinary cellular type, with floors on every frame and having the side longitudinals oil-tight and continuous. The center vertical keel would be tight. The wing parts of the double bottom would be for water ballast and stabilising. An arrangement of piping is shown on the section, Plate 2, connecting each side hold with the wing compartments of the double bottom on the opposite side, so arranged that in case of injury by collision the flooding water would flow through a ten-inch pipe covered by a grating and, raising a flap valve, flow into a longitudinal pipe having branches with flap valves in all the wing compartments on that side. Thus the four wing compartments would be flooded and the vessel kept nearly on an even keel. The bilge pumps would draw from this longitudinal pipe to drain the side holds. With a bulk cargo, like grain or coal, these pipes would probably choke, but with general cargoes they would be automatic. Only the cargo in the damaged hold need suffer. The wing compartments of the double bottom would take the place of the opposite hold for straightening the vessel.

The most difficult part of the problem is that connected with the handling of the cargo to and from the holds. A seaman likes to have ropes, and the more there are of them and the longer they are the better he is pleased, and his fixed habits and thoughts regarding the operation of handling cargo are not easily altered. There was a time in the history of the lumber trade when one winch at each loading point was considered proper. There was a topping boom and a yard-arm boom and a hoisting winch—a survival and adaptation of square-rigger methods. A seaman was stationed, when discharging, to take in the slack on the fall from the outswung boom; then he took a turn around a bollard while the winch lowered the load, which swung out as the weight came on the fall of the outswung boom; when the load was clear over the dock, he surged the fall around the bollard as the load descended. Forty years ago we had a hard time convincing the



Proposed Lumber & Gen. Freight Str.
420'-0" x 60'-0" x 28'-0" Moulded dimensions
Scale 1/16" = 1' Dec. 8th 1914
G. W. Dickie. J. S. Dickie.
24 California St.
San Francisco

Plate 1.

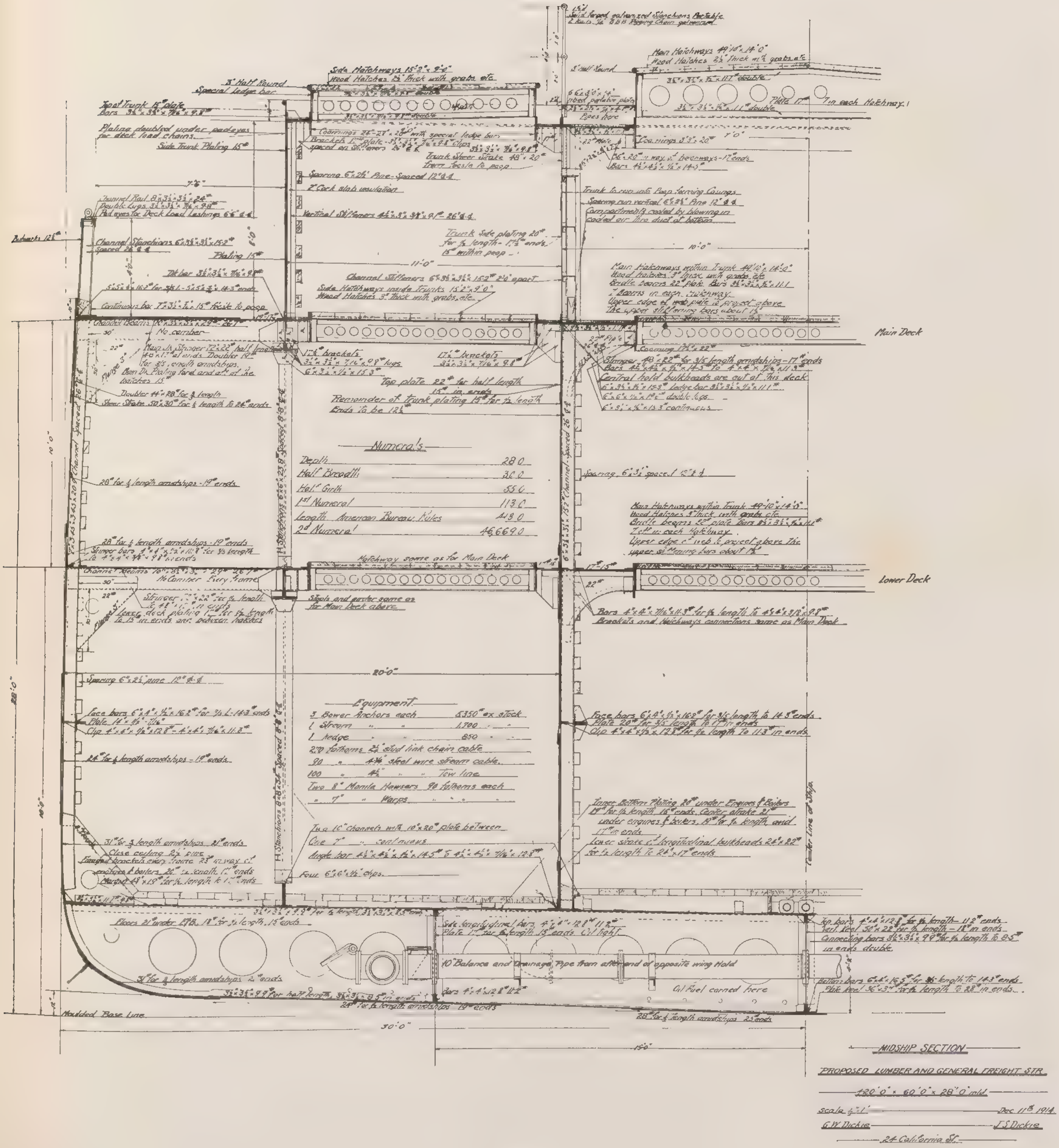
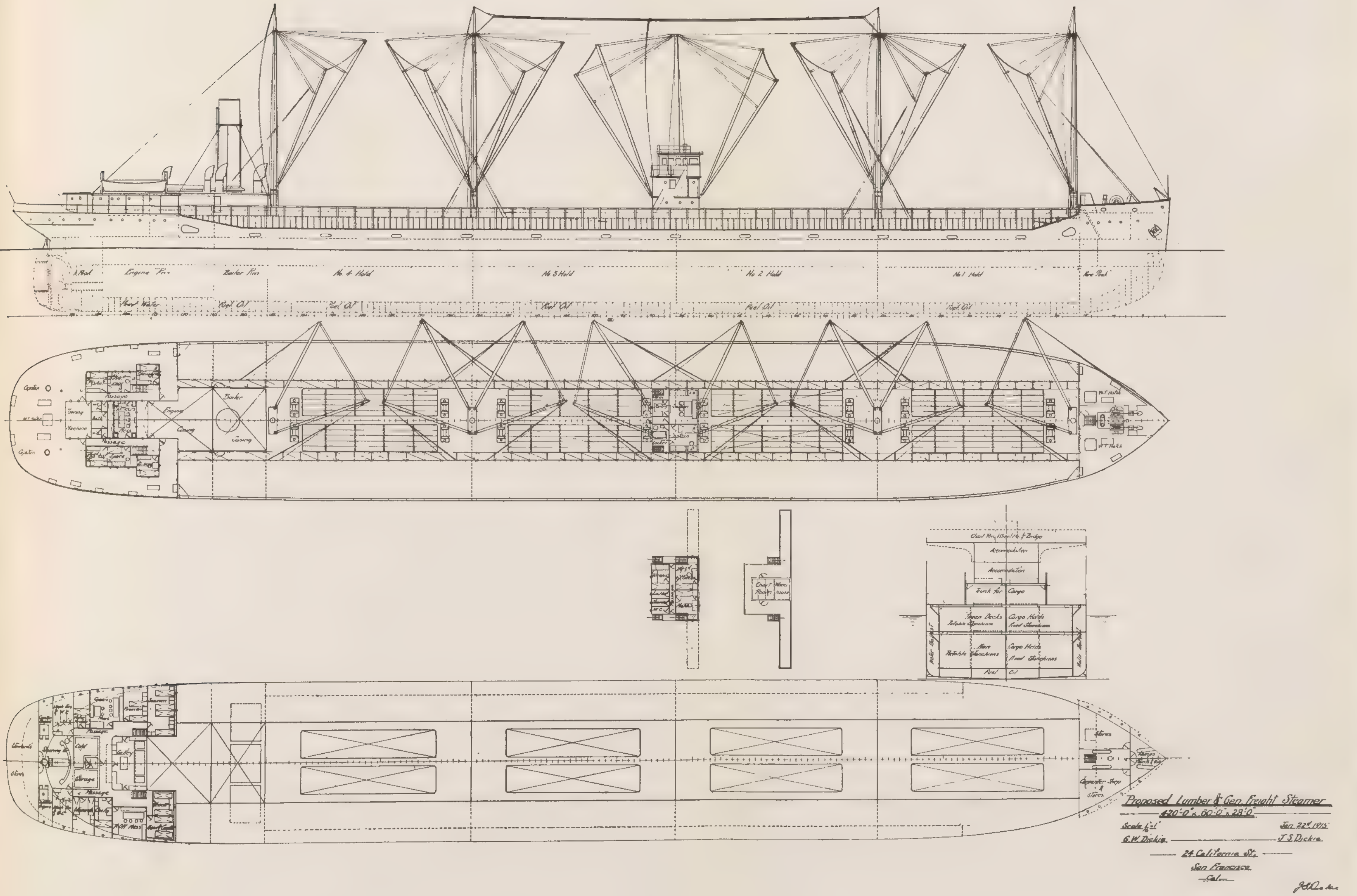

Main Deck
Lower Deck
Moulded Base Line
Numerals
Depth 28.0
Half Breadth 30.0
Half Girth 55.0
1st Numeral 113.0
Length American Bureau Rules 413.0
2d Numeral 46,669.0
Equipment
3 Bower Anchors each 5350# ex stock
1 Stream " " 1,700
1 kedge " " 850
270 fathoms 2¼" stud link chain cable
Two 8" Manila Hawsers 90 fathoms each
Hatchway same as for Main Deck
Stools and girder same as for Main Deck above
Top plate 22# for half length 15# in ends
Remainder of trunk plating 15# for ½ length Ends to be 12½#
10" Balance and Drainage Pipe from after end of opposite wing Hold
Oil Fuel carried here
Bottom bars 6"×4"×16.5# for ⅗ length to 14.3# ends
Plate keel 36"×3" for ½ length to 28# in ends
MIDSHIP SECTION
PROPOSED LUMBER AND GENERAL FREIGHT STR
420'0" × 60'0" × 28'0" mld
scale ½"=1'
Dec 11th 1914
G.W. Dickie
J.S. Dickie
24 California St.
San Francisco

Plate 2.



No. 4 Hold
No. 3 Hold
No. 2 Hold
No. 1 Hold
Fore Peak
Engine Rm
Boiler Rm
Fuel Oil
Boiler
Engine
Casing
Trunk for Cargo
Cargo Holds
Fuel Oil
Stores
Proposed Lumber & Gen. Freight Steamer
420'-0" x 60'-0" x 28'-0"
Scale 1/16" = 1'
Jan 22nd 1915
G. W. Dickie
J. S. Dickie
24 California St.
San Francisco
Cal.

Plate 3.

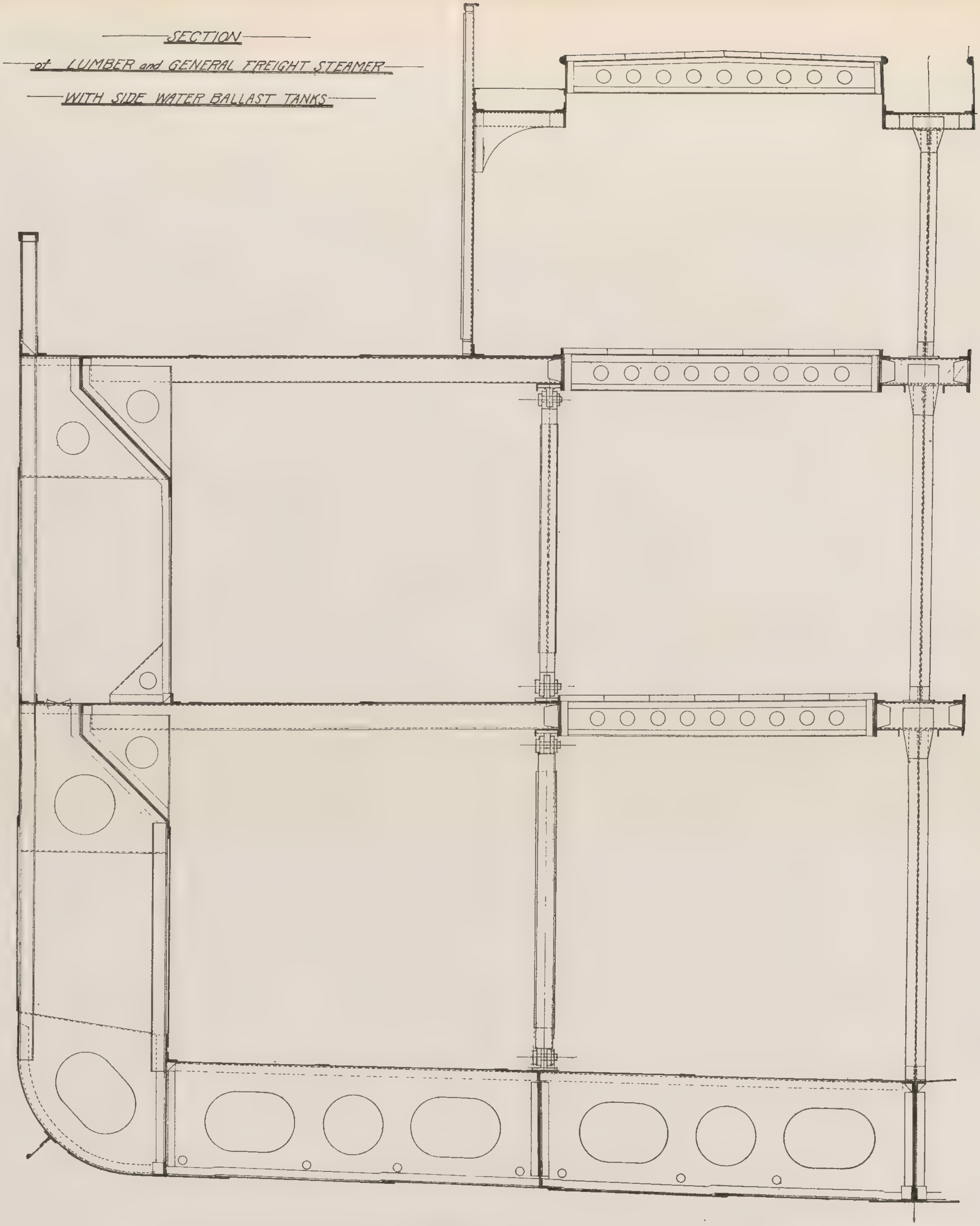

SECTION
of LUMBER and GENERAL FREIGHT STEAMER
WITH SIDE WATER BALLAST TANKS

Plate 4.

lumbermen that they could do this work twice as quickly if they installed two winches so arranged that one man could operate both, taking in the slack fall on one while the other was hoisting the load to a point high enough to allow of this winch being reversed to permit the load to swing out over the deck, when the other would lower it. We had this arrangement working in several ships before the lumbermen could be brought to see its advantages for their work. Now to persuade them that it is better to go back to the single winch and a single boom with but little rigging is likely to prove a very difficult task. Nevertheless, we think the method of handling not only the lumber but also the general cargo outlined on our plans will be more effective, consume much less power, and be cheaper in every way than the methods now in use. In brief, we propose to fit two masts, without rake, each serving two sets of hold groups. The masts, therefore, will step on bulkheads. They will be 26 inches in diameter, without taper to the rigging band, which would be about 50 feet above the trunk top. The goose-neck band would be about 16 feet above the trunk top. Above the rigging band would be a taper pole to carry the wireless aerial. At the masts, the sides of the trunk would be carried up about 12 feet high for a distance of about 22 feet and decked over with arches at ends and masts. On the trunk deck in each end of these structures would be a steam winch so placed that the winchman could see down the hatch adjacent. There would be 4 horizontal cargo booms. There would be 3 shrouds each side, attached to the top of the trunk extension at each mast. There would be a heavy forestay, springstay and main backstay to the after-house. The swing booms of steel, built up in box sections, with a trolley inside, would be suspended from the masts by double heavy wire guys adjustable by turnbuckles. They would be about 65 feet long. The hoisting rope is fast at the outer end of the boom, passes over the outer sheave of the trolley, down around the sheave in the hoisting block, thence up to and over the inner sheave of the trolley to the goose-neck, where it passes over a sheave leading it down on the axis of revolution of the boom; from this point it is led to the steam-winch drum. The goose-neck pin forms a steadyment bearing and swings with the boom;

the pin is continued up as a hollow shaft to the rigging band, where it carries and revolves with the attachments for the boom guys. The entire boom and guys are to be carried by roller bearings at the rigging band. The swinging gear consists of a fixed, steel-toothed, circular rack of about 10 feet radius and 150 degrees in length, secured to solid framing on the top of the winch house. A steel pinion carried by the boom and worked through suitable gearing by a 4-horsepower motor, the control for which will be carried to the hand of the winchman, will engage the circular rack. For traversing the load along the boom, a wire rope will attach to the outer end of the trolley, pass under a sheave at the outer end of the boom and then pass inboard along the boom to a drum mounted on it. A similar wire rope will attach to the inner end of the trolley, pass under a sheave at the inner end of the boom and then lead to the drum, taking it on the opposite side from the first rope, so that it will pay in on one side and out on the other. This drum will be worked through suitable gearing by a 4-horsepower motor, the control for which will be brought to the hand of the winchman. The booms are shown about 16 feet above the trunk top, which we consider high enough for any sling load likely to be handled. They could be placed considerably higher if necessary.

In taking in cargo, with the above arrangement, from a barge alongside or from the dock, the boom is swung out, the cargo block is lowered and hooked into the sling, the load is then hoisted and, as soon as it is clear of the dock, the winchman begins swinging the boom in while the load is still hoisting. He can, at the same time, traverse the trolley on the boom, so that he can lower the load as soon as the boom is fairly over the hatch. He lifts, swings, traverses, lowers, and finally deposits the load just where it is wanted. In the arrangement shown, the holds are about 75 ft. long and the hatches over the lumber holds are about 50 feet, so that if, say, sling loads of 24-foot stuff are being loaded, the first load can be placed so that it butts right up against the bulkhead at one end of the hold, the next would be placed alongside it, and so on till that end is filled one sling-load deep. Then the other end would be filled in the same way, and then the middle. In this way,

tier upon tier would be placed until the hold had been filled. The present method, where the load is run up some fifty feet or more by one boom and then swung on another and by it landed in the hold or on the deck, is spectacular and apparently fast, but it has no control of the fore-and-aft position of the load it is to deposit and necessitates much handling of the sling loads; and while the load moves fast, it also moves through a great distance. The method proposed involves no more movement than is just necessary to get the load into position.

It will be noticed that the rigging is carried to the side of the trunk and the bridge is carried on a cantilever, so that there is no obstruction to the loading of any length of lumber on the deck.

When this type of vessel has loaded lumber at one of the lumber ports and has returned, say, to San Francisco with all the holds designated for lumber full and a full deck load, then, as the hatches to the side holds are trunked through the deck load, there is nothing to interfere with the handling of general cargo into the side holds, and it can go on without interfering with the cargo already stowed. The cargo handling appliances above described would be used for handling the general freight into the side holds, and the work would be done in less time than with the usual gear and with only half the steam consumption for the winches. This type would have the advantage of being able to deliver any considerable consignment of cargo to a port without disturbing that consigned to another. This design is, we think, ideal for a vessel that is required to carry both lumber and general freight eastward.

Where it is desired to carry a full lumber cargo eastward, and no general freight as a rule, and a full cargo of general freight on the return trip, a somewhat different type would be evolved by consideration of the peculiarities of the trade. This type is shown on Plates 3 and 4 and is of the same general dimensions as the first. For a full cargo of lumber, the three holds in the breadth have many disadvantages. The longitudinal bulkheads were, therefore, moved out to the sides, forming side ballast tanks, and were so constructed as to avoid hold obstruction due to beam and bilge brackets and, at the same time, carry a practically continuous girder from the outer bottom plating to the main deck.

The double bottom extends from the longitudinal bulkhead on one side to the one on the other side, and from the forepeak bulkhead to the after-peak bulkhead. 300 feet of the length would be used for stowing oil fuel and will carry 10,000 barrels, which, with the settling tanks of about 1000 barrels collective capacity, will give sufficient fuel for a round trip from San Francisco to New York, on the assumption that a high-speed steam turbine with geared or electric drive is installed, or a Diesel engine. In the latter case the vessel could even go to a British port and return. The space, 5 feet, between the outer skin and the longitudinal bulkheads would be reserved for water ballast and has a capacity of about 1500 tons, and this, with the fuel bunkers filled, would put her in good trim for a port to port trip, light, on this coast.

The trunk would be about 30 feet wide and 8 feet high, with stiffeners on the outside. Every third one of these would be a 6-inch channel with a heavy timber of iron bark bolted in its bottom and would be carried up 4 feet above the trunk to support the deck load and carry the chain rail. The top rail would be a channel. The deck load would be carried 12 feet high and securely held down by chains rove through cast-steel corner-saddles, at the corners of the deck load, and hove up with turnbuckles.

There would be eight hatches, as shown, about 46 feet long and 10 feet wide in the clear; and to facilitate stowage, the hold pillars alongside the hatches would be releasable at the heels and would be triced up to the under-side of the girder under the deck above; the center row of stanchions would be fixed. The lumber capacity of this vessel would be 5,000,000 feet, of which 1,000,000 would be in each of four holds and 1,000,000 on deck. The capacity for measurement freight under deck would be 9000 tons @ 40 cu. ft.

On this plan we have shown the usual arrangements for handling cargo using four masts and one derrick pole. The rigging is all kept clear of the sides of the ship. The bridge is carried on cantilevers, and the decks are entirely free at the sides for the deck load. Each hold will be loaded or unloaded from both ends of two hatches, so that there will be 8 loading points, necessitating the use of 16 winches and 8 winchmen.

This does not differ from the customary arrangement, except in the number of loading points.

The arrangement shown and described for the first type could be applied here with advantage. There would be 4 winches and 8 motors instead of 16 winches, and there would be 4 winchmen instead of 8. As the amount of hoisting is about 1 to 4, the amount of steam used would be about 1 to 4, and the expenditure for hoisting rope would be about 1 to 8. Still, some owners would prefer the old way because they know what it is and their men know what it is.

We think it unquestionable that the character of the intercoast freight trade demands a special type of vessel, and our study of it has brought us to the type described, which is now before the Congress. Some of the shipowners and their representatives have been invited here to take part in the discussion that would follow a paper of this kind. Some necessary requirements probably have been overlooked in the preparation of these outline designs. If these are pointed out in the course of the discussion, the author or some one else may be helped to produce a vessel that will include all the characteristics she should have in order to prove successful in the Coast-to-Coast trade.

DISCUSSION

Mr. E. U. Wheelock* in a letter to the author said there was no question but that the arrangement of gears, booms, etc., which was provided would have a great many advantages over the older methods. He desired, however, to point out what appeared to be certain disadvantages of the arrangement. Mr. Wheelock.

A steamer for general cargo service between Pacific and Atlantic ports would have to load and discharge at different docks, mills, yards, etc., and any arrangement of gears, booms, etc., would of necessity have to be flexible enough to admit of the vessel loading and discharging without any unusual delay or extra work. Conditions are often such that but a small part of the wharf space can be devoted to a single order. This makes it necessary to pile up the material for this order, sometimes to a height of 18 to 25 ft. above the cap of the dock. He apprehended that a vessel with the horizontal booms of the construction outlined would have considerable difficulty in attempting to take on cargo under these conditions, particularly if they had a rise and fall of tide averaging from 5 to 7 ft. For, should the vessel arrive at low

*Ass't Manager, The Chas. Nelson Co., San Francisco, Calif.

Mr. Wheelock. tide and find the lumber stacked up to a considerable height above the cap of the wharf, and having in mind that the design does not provide for any means of raising or lowering the heel of the booms, which have a straight horizontal sweep, the extreme difference between the water level and the pile of lumber to be loaded would prevent starting to work until possibly some of the lumber had been lowered onto the dock, or until the tide changed and floated the vessel higher. The same difficulty would occur at some places in discharging, for the reason that a steamer would arrive immediately prior to a Sunday or a holiday, and would want the privilege of rough-piling the lumber. This would mean that the stock would have to be, in some instances, piled very high on the dock.

According to the writer's understanding of the design, the heels of the boom are permanently fastened at approximately 16 ft. above the deck of the ship, which, as noted, would limit the operation of the boom to such stock as was within reach of it when it was swung over the dock at this height above the deck. In the handling of lumber, this would be the greatest handicap under which this rig would have to work.

In handling general cargo, a great many of the public docks are constructed so that the warehouses are within 14 to 16 ft. from the cap of the wharf, and in some instances, only the width of a railroad track. This would mean that the discharging of the general cargo with this horizontal boom would practically all have to be accomplished with the trolley operating at the extreme outer end of the boom, and it appeared to the writer that awkward handling would result on account of the distance of the load from the control at the heel of the boom. He thought the lack of flexibility in the operation of the horizontal boom would constitute its weakest point. It has always seemed that the greatest efficiency is accomplished when the machinery or tools used had the greatest amount of flexibility, keeping in mind, all of the time, the necessity for simplicity in both design and operations. Could the difficulties, as outlined, be overcome, it would certainly appear as though the horizontal swinging boom would provide practically an ideal rig for miscellaneous cargo use.

Mr. Gleason. **Naval Constructor Henry M. Gleason,**‡ Mem. Soc. N. A. & M. E., asked why fuel-oil storage should extend over approximately 300 ft. of the vessel's length instead of concentrating it near the boiler.

Mr. French. **Mr. James French*.** Mem. Inst. Naval Arch., London, expressed the opinion that in case of collision a common valve in the 10-in. pipe connecting the wing parts of the double bottom would be better than the flap valve. He considered the wing water-ballast tanks a real source of danger.

Mr. Dickie. **Mr. Dickie** said that the distribution of fuel oil along the bottom aided materially in stabilizing, as it places the ballast where it is needed.

‡ U. S. Navy Yard, Mare Island, Calif.

* Glasgow, Scotland.

The pounding of waves going up the Pacific Coast is quite serious at times, hence the need of distributing the ballast. Mr. Dickie.

In reply to the statement of Mr. Wheelock as to the disadvantage of a fixed horizontal boom he said that the boom could be placed at any desired height. He then stated that few realized the expenditure for new rope the present system of unloading required; $700 or $800 per month is frequently paid out for this item. The ropes are drawn over the edges of the hatches and are soon cut to pieces. The present methods of handling cargo, in general, seem very crude. It is a problem which can very profitably be studied. Some of the methods seem almost barbaric.

As to the rate of unloading lumber, Mr. Dickie recently observed the unloading of a cargo of lumber from the "Adeline Smith", 1,960,000 ft. were taken off from 10:30 A. M. Saturday to 1:30 A. M. Sunday morning. During several hours of the day the unloading progressed at the rate of about 280,000 feet per hour.

Paper No. 202

THE DEVELOPMENT OF THE SAIL YACHT, STEAM YACHT AND MOTOR YACHT IN AMERICAN WATERS.

By

WILLIAM GARDNER, Mem. S. N. A. & M. E.
New York, N. Y., U. S. A.

THE SAIL YACHT.

In taking up the development of the American Sailing Yacht, I will start with the schooner "America", 1851, as this was the first boat to give us an International reputation in yacht designing. The "America" and her sisters, the "Una" and "Mary Taylor", all from the board of George Steers, started a new era in the form of models. Before this, yachts were built with the cod's head and mackerel tail. The bows were short, full and bluff, and the sterns long, and often fine. The "America" and her sisters were given long, fine bows, 55% to 60%, and correspondingly short, but fine sterns. This change brought the center of buoyancy farther aft and produced much faster boats, especially to windward. The angle of entrance was finer, and the lee side easier and more effective in holding on. Better sea-boats also resulted. The ballast coming further aft, caused a concentration of the weights and brought the center of gravity of the hull and ballast in nearly the same vertical line. This distribution of bow and stern became universal in all types and has remained to the present day.

The "America" was a keel boat, of good draft, full midship section and generous displacement. She had a decided drag to her keel, which brought the center of her lateral plane and the center of effort of her sails well aft, in their proper place. This combination produced a perfect balance and made

a boat easy to steer under all conditions. As a result of her success, a distinct type was established in the larger class and she was soon followed by such splendid boats as "Sappho", "Dauntless", "Dreadnought", "Rambler", "Enchantress", and others. In fact, some of the large racing and most of the large cruising boats of few years ago differ from her very little in model,—longer overhangs and the changes incidental to refinements in ballasting and rig being the principal ones.

After the "America", another type came into existence. These were known as the "Center-board boats". So many were built in all sizes, they were eventually looked upon as the national type. Their principal characteristics were short overhangs, good beam, moderate draft, and a large center-board to prevent leeway going to windward. As time went on, the beam was increased to give sail carrying power, and the draft decreased, probably to reduce surface and make an easier form down wind; at the same time, freeboard was decreased to save weight. To get headroom, cabin houses were placed over owner's accommodations. There was a great prejudice against outside ballast, as it was thought that it made the boat loggy, so all ballast was stowed inside. These boats had great initial stability, carried large rigs, and were very fast in smooth water and down wind.

In the races for the America's Cup, the center-board has played a very important part. In the race sailed in 1870 against the schooner "Cambria", the center-board schooner "Magic" won. In 1871, in the race against the schooner "Livonia", the center-board schooner "Columbia" won the first, and the keel schooner "Sappho" won the other two. In 1876, the center-board schooner "Madeline" defeated the schooner "Countess of Dufferin", and in 1881, the center-board sloop "Mischief" defeated the sloop "Atalanta". The "Puritan", "Mayflower", "Volunteer" and "Vigilant" were also center-boards, while the "Defender", "Columbia" and "Reliance" were keel.

The New York Yacht Club confined itself to cabin boats only. In the smaller clubs, a very interesting class developed. They were open boats and were known as "Sandbaggers". They had separate rules both for measurement and sail-

ing. For time allowance, they took either a mean length, viz., half the sum of the over-all length and load water-line, or a given distance above the load water-line. Shifting ballast was allowed, with no limit to the crew. The result was a plumb-ended, broad, shallow boat of small displacement, light hull and enormous sail plan. They required exceptional skill to sail, and furnished great sport; capsizes were frequent, but they seldom sank, as the sand bags generally went overboard. These boats have now disappeared.

In the cabin classes, various rules of measurement for time allowance were in vogue between 1851 and 1883. Sometimes each club had a separate rule of its own. Just what effect these rules had on design, it is difficult to tell. Displacement was used at one time and cubic contents another. The former would encourage small displacement and the latter low freeboard—both of which existed. Whatever the cause, the shallow draft type developed, and as it progressed, the initial stability became greater, while the range decreased. In 1876, the "Mohawk", 121 ft. load water-line, 30 ft. 4 in. beam, and only 6 ft. draft, capsized in New York Harbor, drowning her owner. This accident drew public attention to the undesirability of the type and the necessity of better measurement rules.

In 1881, James Coates, Jr., sent the keel cutter "Madge" from Scotland to this country to race. Much to the surprise of everyone, she was successful. The "Madge" was built to take advantage of the English measurement rules, and she raced successfully there before coming here. She had a load water-line length of 39 ft. 6 in., a beam of 7 ft. 6 in., and a draft of 8 ft. Her midship section was full and her displacement heavy. All her ballast was lead in one piece, fastened on the outside, and her hull was very light. While she was safe and non-capsizable, she was wet in rough water and cramped in beam. Her success was due to her ballasting, to the great refinement of hull construction, rigging and sails, and to the excellent way in which she was handled. Her influence on yacht designing was greater than that of any boat since the "America". The country was ripe for a change in type. She demonstrated that a boat could have a large displacement and be absolutely

non-capsizable and still be fast. It was appreciated by those yachtsmen who studied the races that she was the development of the English rule that penalized beam, and they believed that a faster and better type, equally safe, could be developed, provided measurement rules could be devised to encourage such a type.

In 1883, the New York and Seawanhaka-Corinthian Yacht Clubs adopted a length and sail-area rule. The New York formula was $\frac{2\,L + \sqrt{S.A.}}{3}$ and the Seawanhaka $\frac{L + \sqrt{S.A.}}{2}$, where L = load water-line and S. A. = sail area. The boats were first classified by the corrected length, but shortly afterwards, for the sake of uniformity, were classified by load water-line only. The time allowance adopted was 50% of the theoretical, it being assumed that the speed of boats varied as the square roots of their load water-line lengths. With this change in the measurement rules, the type of boat changed. Our designers did not follow the "Madge" model closely, but gave the boats a generous beam and draft, coupled with a wholesome freeboard and displacement. At the same time, the rig, sails and ballasting were refined.

In 1885, Sir Richard Sutton challenged for the America's Cup, with the cutter "Genesta". This boat was of the same type as the "Madge", having been built to suit the same measurement rules. To meet her, Mr. Burgess designed in the "Puritan" a boat of the new type. She had less beam, and more draft and displacement than the typical sloop, but on the other hand, was wider and shallower than "Genesta". Her ballast was nearly all on the keel. She thus had both natural and artificial stability. While her draft was less than "Genesta", her large center-board gave her ample holding on power. Above the deck, the complete English cutter rig was adopted.

The succeeding Cup boats, "Mayflower" and "Volunteer", were of this type, but were given greater length and draft.

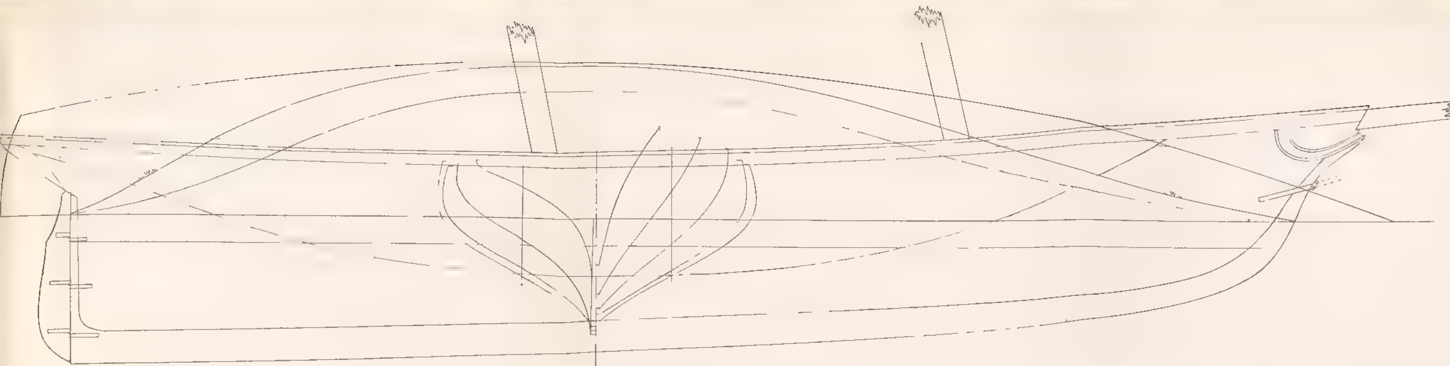
In 1889, the famous 40-ft. class was started. This class was the beginning of the first keen class racing. These boats were nearly all of the keel type, with good beam, deep draft, heavy lead keels, and enormous sail area. Among this fleet there suddenly appeared a clean-lined, graceful boat, moderate in dimen-

sions and sail area, but far more beautiful than any of the others, and she proved the fastest of the fleet. This boat was the "Minerva", designed by Fife, that had come from England on her own bottom and was sailed by the now famous Charlie Barr. She represented the English idea of a compromise type, having greater beam and draft than "Madge", with less displacement.

In 1891, a new class, the 46-footers, was formed. These boats, generally, showed the influence of the "Minerva". Among them, however, the "Gloriana" soon appeared. This boat, the product of N. G. Herreshoff, and the forerunner of his successful Cup Defenders, introduced entirely new principles in design. Her water-line length was 46 ft. and her over-all, 71 ft., about 9 ft. longer over all than any of her competitors. She had no forefoot whatever, but had a long side, with a comparatively full load water-line. Her beam was slightly less than the others and her draft about the same, but her overhangs were lower, and when she heeled, had a listed water-line much in excess of 46 ft. The water went under her rather than around her, and the long side gave her great stability. This, coupled with an extremely light and refined hull and rigging, made her a phenomenal success.

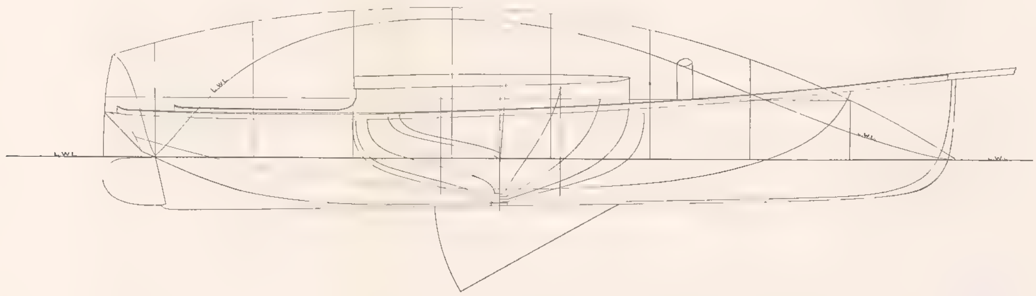
In this same year, Herreshoff brought out another boat, the "Dilemma", quite as original in design as "Gloriana", and possessing many of her features. The relative displacement, however, was very much less and the hull much shallower. Attached to the hull was a bronze plate fin, and at the bottom of this fin, a lead bulb. These two boats had a decided influence on the designing for some time to come. The fin keels eventually dropped out. Their influence, however, remained, and was noticeable in the extreme thinning of the keel half way between the hull proper and the lead, as shown in "Defender", "Columbia", "Reliance", and many others.

In 1890, the New York Yacht Club adopted the Seawanhaka rule, viz., $\frac{L + \sqrt{S.A.}}{2}$. The rules were now uniform in all the important clubs. The adoption of the "Gloriana" form, coupled with refinement of construction, made it advantageous to take large sail areas and give the time allowance. As a consequence, the rule was changed in 1896, so that all boats were classified



"AMERICA"

No. 1.



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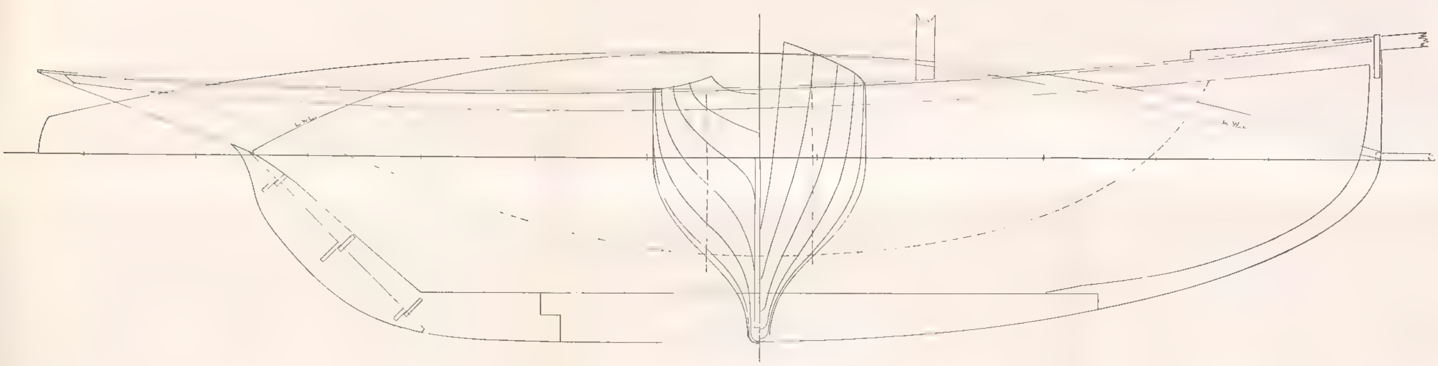
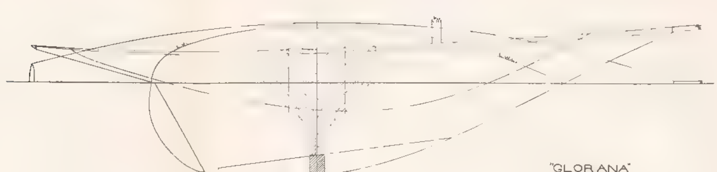


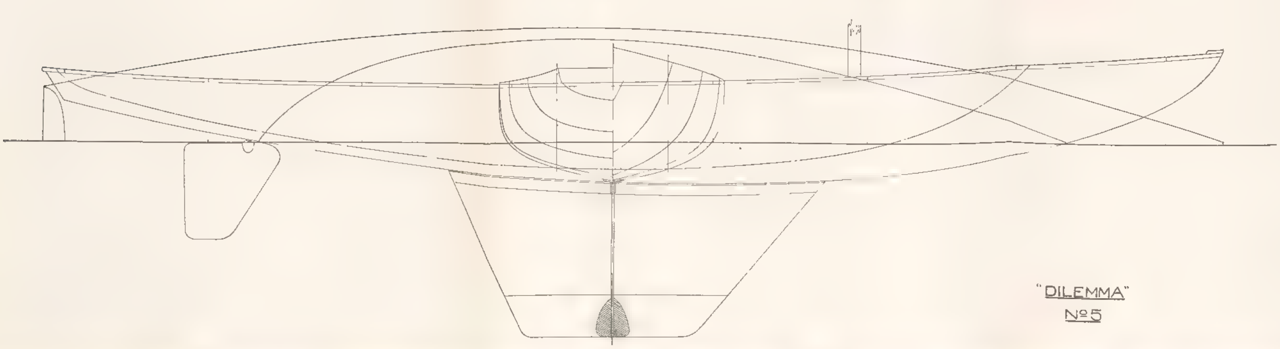
"GENESTA"

No. 3



"GLORANA"

No. 4

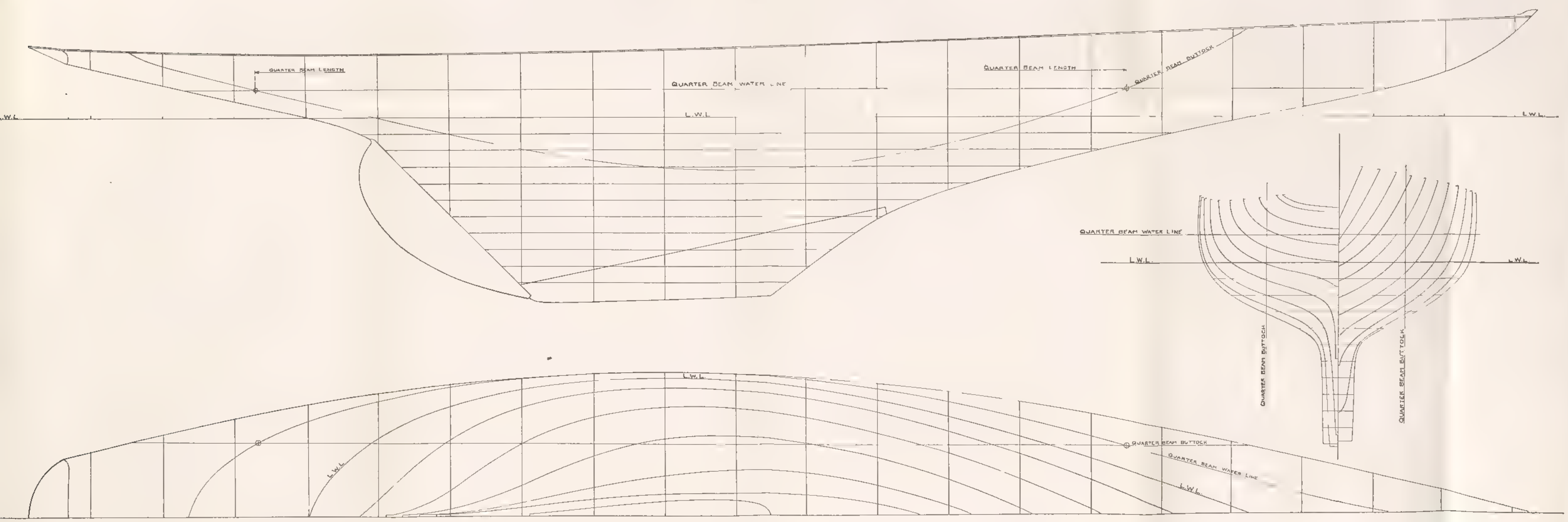


"DILEMMA"

No. 5


L.W.L.
BUTTOCK
INCLINED WATER LINE

Nº 6.


QUARTER BEAM LENGTH
QUARTER BEAM WATER LINE
QUARTER BEAM BUTTOCK
L.W.L.

Nº 7

by corrected length. This eliminated time allowance between boats built to the top of a class. As was anticipated, the new boats were built longer on the water-line, with finer and easier hulls, and a much smaller sail area. The rule, however, was not yet perfect; it had its loop holes. Designers had not forgotten the value of sail area. As length was measured on the load water-line, it was soon found possible, by filling the water-line and lowering the overhangs, to increase the listed length. The load water-line was consequently shortened, displacement reduced, and the sail area increased. The "Cartoon", one of the most extreme, had a load water-line length of 25 ft. and a beam of 10 ft. upright. When listed, she had a heeled water-line of 47 ft. and a beam of 5 ft. 3 in. As this rule evasion continued, the type of boat deteriorated until it became almost impossible to hold the hulls together in rough water, the pounding was so great. It was evident that a decided change must be made in the rules to save yacht racing, and the change must be of such a nature that a wholesome boat would be produced and rule cheating prevented. A great deal of study and investigation was given the subject, and the best authorities on both sides of the Atlantic were consulted. As a result, in 1903, the present rule, slightly different in form, but essentially the same, was adopted. The rule as it now stands is, Rating $= .18 \dfrac{L \times \sqrt{S}}{\sqrt[3]{D}}$ where L = load water-line; S = sail area; D = displacement in cu. ft. The rule is protected from evasion by limitation. To prevent excessive listed length, a measurement is taken parallel with the L. W. L., 10% of the water-line beam above the L. W. L., and ¼ of the L. W. L. beam out from the middle line. If this exceeds $(100 - \sqrt{\text{L. W. L.}})$ per cent of the L. W. L., half the excess is added to L. W. L. in the formula. If draft exceeds 16% of L. W. L. + 1.75, such excess shall be multiplied by 3 and added to rating. If $\sqrt[3]{D}$ exceeds 20% of L. W. L. + .5, such excess of displacement shall not be used in formula. If you will examine the formula, you will see that R varies as the $\sqrt{S}$. In other words, it is a sail area rule, with limitations and restrictions. You can build any sized hull you please, for a given class, provided you do not vary the sail area or the ratio of L to the $\sqrt[3]{D}$. Or, if you wish to build a large, roomy boat, having

maximum cruising accommodations, you can increase the displacement within the limitations and get a corresponding increase in sail area or power. This at first glance would seem unwise. As a fact, filling the sections increases the displacement faster than the surface; consequently, the ratio of surface to sail is smaller in the bulkier boat, and this ratio is important in light winds. Furthermore, a large displacement, coupled with small surface, seems to have an advantage in light winds, even when the ratio of sail to surface is slightly less than the finer-lined opponent. In the working out of the rule, wide differences in the quantities taken often lead to almost identical results. The designer, in consequence, has great latitude in his selection of quantities. The success of the boat seems to depend not so much on the quantities taken, as on the refinement of the individual design, the balance, the trim at all times, the shape and set of the sails, and the refinement of construction.

Two boats in Class "P" finished the season quite near together in total winnings. One was 35.54 L. W. L., had a displacement of 559 cu. ft. and a sail area of 1568 sq. ft. The other had a L. W. L. of 32.5 ft., displacement of 300 cu. ft., and a sail area of 1254 sq. ft. A boat that afterwards defeated both of them had a L. W. L. of 34 ft., displacement of 381 cu. ft., and a sail area of 1355 sq. ft.

The results of this rule have been very gratifying. The fastest boats we have today, and they are very fast, have no undesirable features—in fact, for racing, they are in every respect the most desirable boats we have ever had. The displacement is ample, but the lines are fine. The overhangs are long, but forward they are now sharp, where once they were flat. The bowsprit, if there is any, is very short, and the boom extends very little over the stern. The sail is in consequence easy to handle, and the area for the sized boat is not large. Efficiency has been studied, so that 1,000 sq. ft. of sail today has at least the propelling power of 1,500 sq. ft. of a few years ago. What the future will bring forth it is hard to tell. There is no indication now that the rule evasions of the past can be repeated. If they should be, however, there is no doubt that immediate steps would be taken to correct the faults in the rule before vested interests could be affected.

In this paper, I have not taken up the designs of the cruising boats. They have followed, in a general way, the lines of the racing boats, except that extremes have been omitted.

The lines of "America", "Genesta", "Gloriana" and "Dilemma" are not absolutely accurate, but are sufficiently so to give a definite idea of the characteristics of the boats.

ILLUSTRATIONS.

Sail Yachts.

1. "America".
2. Typical center-board boat of the Seventies.
3. "Genesta". This boat was similar to "Madge", but was less extreme in draft and narrowness.
4. "Gloriana".
5. "Dilemma".
6. Lines of a successful boat, showing the compromise between the "Gloriana" and "Dilemma" midship sections, and the great gain in length of the inclined water line, due to the full end sections.
7. Lines of a successful boat under the present measurement rules, showing position of quarter beam points of measurement.

THE STEAM YACHT.

The principal development of the American steam yacht has taken place since 1890. A few steel yachts were in existence at that time, and they were very good examples of their kind, but the majority were built of wood. The typical steam yacht of the day had an easy midship section, long fine ends, and low free-board. A pilot-house was placed forward, and a cabin house aft, which ran over the machinery space and accommodations. It is needless to say they were not good sea-boats and their cruising was confined mainly to protected waters. The auxiliaries, "Sagamore" and "Sultana", boats of a different type, being about our only steam yachts to cruise off-shore. In England, the moment a boat leaves a harbor, she is in the open sea. As a consequence, a strong sea-going type has been developed. It was useless to give a boat high speed, as it seldom could be maintained.

Here, conditions are entirely different. We have the most beautiful yachting waters in the world. Long Island Sound, the Chesapeake Bay, the Hudson and St. Lawrence Rivers, the coast of Massachusetts and Maine, and the thousands of miles of inland lakes and rivers give us waters that are ideal for cruising. Even the waters off our coast are seldom rough in summer, and when they are, the numerous harbors close together give one plenty of places to run in before a sea can make up.

Many of our men of wealth have been closely confined to business, with their time for yachting limited.. As a consequence, speed has frequently been a more important consideration than sea-worthiness, and our smooth waters have made speed practical.

In the process of evolution, three types of steam yachts have been developed: The Express Yacht, the Coastwise Yacht, and the Sea-going Cruiser. The small steam yachts and fast launches of a few years ago are rapidly disappearing, none are now being built, the motor boats having superseded them.

The Express Yachts are long and narrow, generally with the flat or torpedo boat stern. The hulls are very light and beautifully built. The propelling power consists of single and twin screws, high-speed, triple-expansion engines or turbines, with light, small tube torpedo-boat boilers. They have small accommodations, the

machinery taking up most of the space below. These boats have become very popular and are used principally for short cruises or to take the owner to and from his place of business and his country home.

The Coastwise Yacht has been the most popular type. The earlier ones had an overhanging bow and stern, fine lines fore and aft, a sharp, easy midship section, moderate beam, and high freeboard. The deck-houses were of mahogany, of moderate size, and the boats were carried low. The construction of the hull was moderately light. The machinery consisted of triple-expansion engines, of high revolution, and the boilers were water-tube, of the torpedo-boat or the heavier screw-joint type. Speed was generally an important consideration. The bunkers and water capacity were small, and the stowage space limited.

Yachting in its earlier days was more of a sport than a recreation, and was indulged in principally by men. As the women became interested in outdoor sports and indulged in them, their interest in yachting increased, until it is now quite usual to see the wives and families of the owners aboard; the families in many cases living there for the entire season, thus making the yacht a floating home.

These changes of conditions have had their influence on design. The yachts have become more luxurious and comfortable. The saloons that were formerly below are now on deck. This has necessitated enlarging the houses. As the houses were enlarged, the promenade space on the sides became contracted, so the roofs of the houses were carried out to the side, forming a shade or promenade deck. On this deck, again, are often placed small houses, forming chart or smoking rooms. Ventilation has been given careful study, and it is now usual to have every room ventilated with an over-head skylight of the lean-to or A-frame type. Artificial ventilation is resorted to as well in many instances. The electric light plants have necessarily increased with the accommodation, and, added to the general lighting, there are often powerful search-lights and decoration belts, as well as large storage batteries. The plumbing has become more elaborate, porcelain or china replacing enameled iron. Many boats are also supplied with some form of cesspool system, the Hermes being very popular. As the boats are often out

early or late in the season, a more elaborate system of heating has been required. As owners find they can absent themselves longer from business, their cruises have naturally become longer, so the bunker capacity has had to be increased. For the same reason, an elaborate cold-storage plant has become necessary. No yacht is well equipped without two launches. The Government now requires heavy life-boats, and there must be smaller boats for general use. A greater quantity of stores and water are also required. The task of the naval architect has become more and more difficult, as all of these improvements have meant additional weights and nearly all of these weights have been high up. To carry these weights and get the proper stability, it has been necessary to increase the beam, fill the midship section, and fill the ends. In many cases these changes have been made without a very great increase in resistance, due to the very valuable experience gained from the experimental model tank at Washington. Ballast is not usual but is sometimes carried, when a disturbance of the accommodation desired by the owner is of more consequence than the slight additional weight to trim, or when a slight adjustment of weights is necessary for steadiness in rough water. Weight is sometimes saved, when ease in a sea-way is not the first consideration, by giving the yacht a straight stem and short stern. Heavy spars, for the purpose of carrying sail, are going out of use. The clipper-bowed boats have two pole masts of moderate dimensions, while the straight stems are generally accompanied with a single signal mast, with a square yard.

As the yachts are becoming more comfortable and luxurious, the demand for high trial-trip speeds is disappearing. The first cost and the cost of maintenance are much greater than they used to be, so coal economy is becoming an important factor. Yachts are seldom run at their maximum speed, and when they are, are under forced draft. The result has been that for the occasional satisfaction of beating another boat or making a fast run, the general cruising must be done under conditions that are far from economical. The boiler under natural draft is not suitable to the engine. The pressure being low, no advantage can be taken of steam expansion, and the one or two low-pressure cylinders do no work and are a drag. The clearances are unneces-

sarily large and the auxiliaries excessive and extravagant. For the well designed boats of today, where the owner has allowed it, the boiler power has been increased, the sizes of the cylinders and the clearances decreased, and the stroke made longer. Twin screws are frequently used, as well as the four-cylinder triple engine. While the Scotch and the large-tube water-tube boilers occasionally appear, the tendency is towards the small-tube or screw-joint type.

The improvements made in the Coastwise yacht apply to an even greater degree to the Sea-going Cruiser, the two types now having many similarities. In the Sea-going yacht, of course, the first consideration is safety, and ease and steadiness at sea. In the best designs, moderately long overhangs are the rule. A great deal of buoyancy is contained in these ends, especially with the full water-line now used. The overhang bow cuts the water easily and lifts the bow at the same time, making it possible to drive the boat with comfort much faster against a head sea than could be done with one having a straight stem. The after overhang is also very effective when running or with a quartering sea. Fortunately, we are not hampered by the various conditions that influence and control the design of a merchant vessel. We can give any form of midship section we please, and any form of fore and aft lines. The proportionate buoyancy above water is much greater in a steam yacht than in a merchant vessel, and the heavy weights are well concentrated amidships. And again, the variable weights, principally coal and water, affect the metacentric height very little. Bilge keels are also used, and are made large and very effective. As a consequence of these things, it is possible to produce a boat of exceptional ease, steadiness, and dryness in a sea-way.

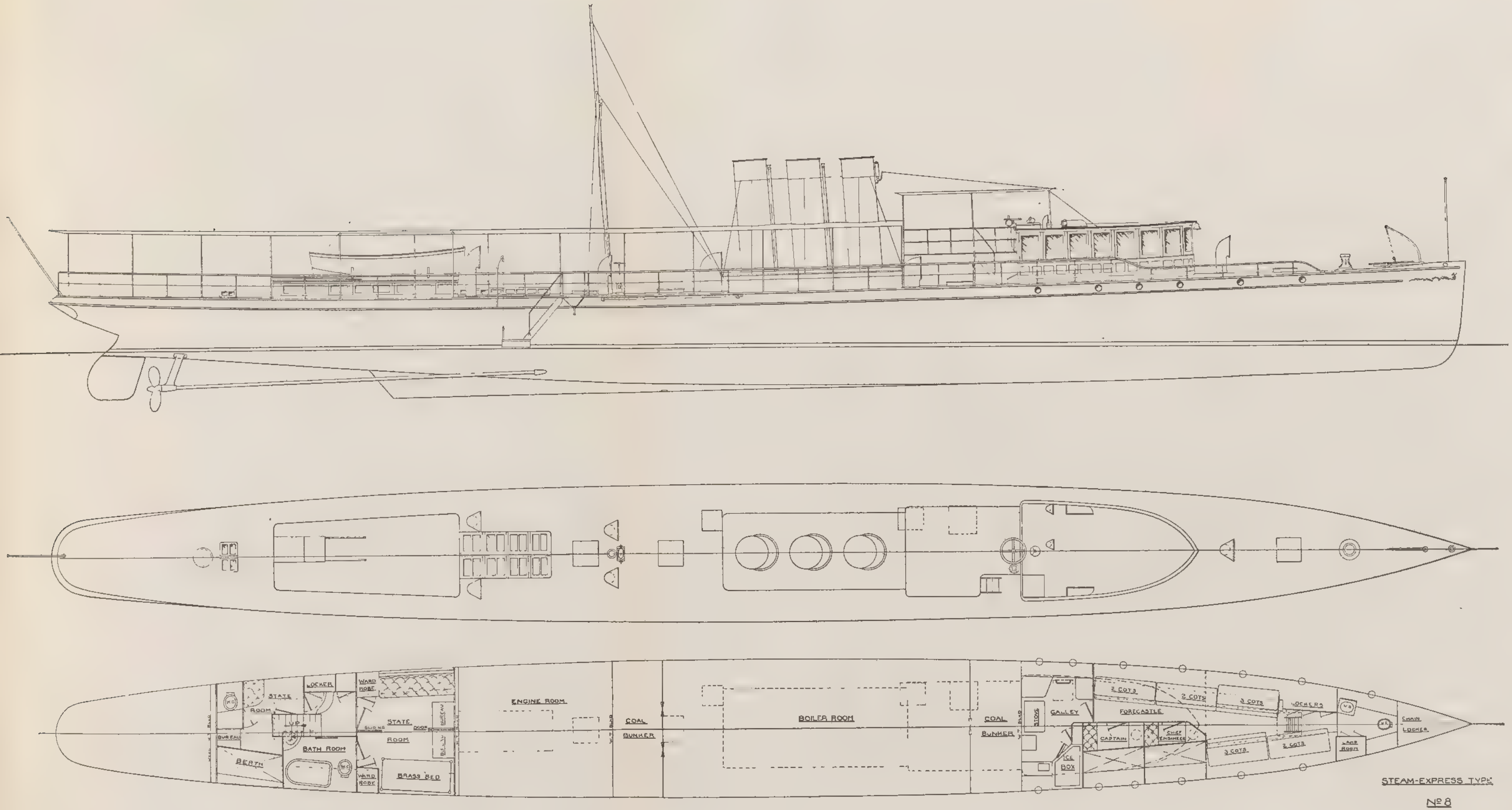
The sub-division is now receiving its proper attention. The usual practice is to have six or seven water-tight bulkheads. First, is the collision; second, at the after end of crews' quarters; third, at after end of officers' quarters; fourth, forward end of boiler room; fifth, between engine and boiler room; sixth, at after end of engine room; seventh, after collision. A water-tight door is usually placed between engine and boiler room, and another from engine room to shaft alley.

In the past, our designers have been criticised for the light-

ness of their construction, and this, with some, maintains today. A few boats have been classified by Lloyd's and other societies, but they have been the exception and not the rule. That our designers have been justified in the scantlings they have used, from the point of structure, has been proved by the very few, if any, structural weaknesses that have developed. The writer has found Lloyd's Rules in excess of the strength necessary, and in several yachts, the bending moments of which he worked out, the maximum stress was well below the amount considered safe for merchant vessels. In spite of this, however, many of our yachts have been too light, as they have seriously lacked durability, and the tendency, I am glad to say, is to use Lloyd's Rules throughout, or at least in the bottom plating and those parts most liable to corrosion. The weakest part of the boat is undoubtedly the water-tight bulkheads, and these, in the future, should be given very great consideration, both in the scantlings and in the workmanship.

We have been very fortunate in regard to the materials available for construction. The Navy Department has demanded very high quality for its use and has developed the manufacture of it. We have, in consequence, been able to obtain this high-grade material at a reasonable cost. It is several years since the writer has built a steam yacht the plating of which has had an elongation of less than 25%, and seldom less than 27%. This material, combined with carefully laid-out double-riveted edges and treble-riveted butts, makes a hull that is remarkably safe from serious damage. Such hulls have been severely rammed, or have been ashore, when a dozen or more plates had eventually to be removed. They have also received other severe damages, but have always reached home, sometimes hundreds of miles away, without serious leak and without the cracking of a single plate.

In the Sea-going yacht, steaming radius is a very important consideration, consequently, large bunker capacity is necessary. It was formerly the practice to carry large quantities of coal on deck when starting on a long voyage, but this is very objectionable, as it raises the center of gravity and makes a bad seaboat. For the same reason, coal economy is very important. Boilers are, in consequence, made large and the engines have



STEAM-EXPRESS TYPE

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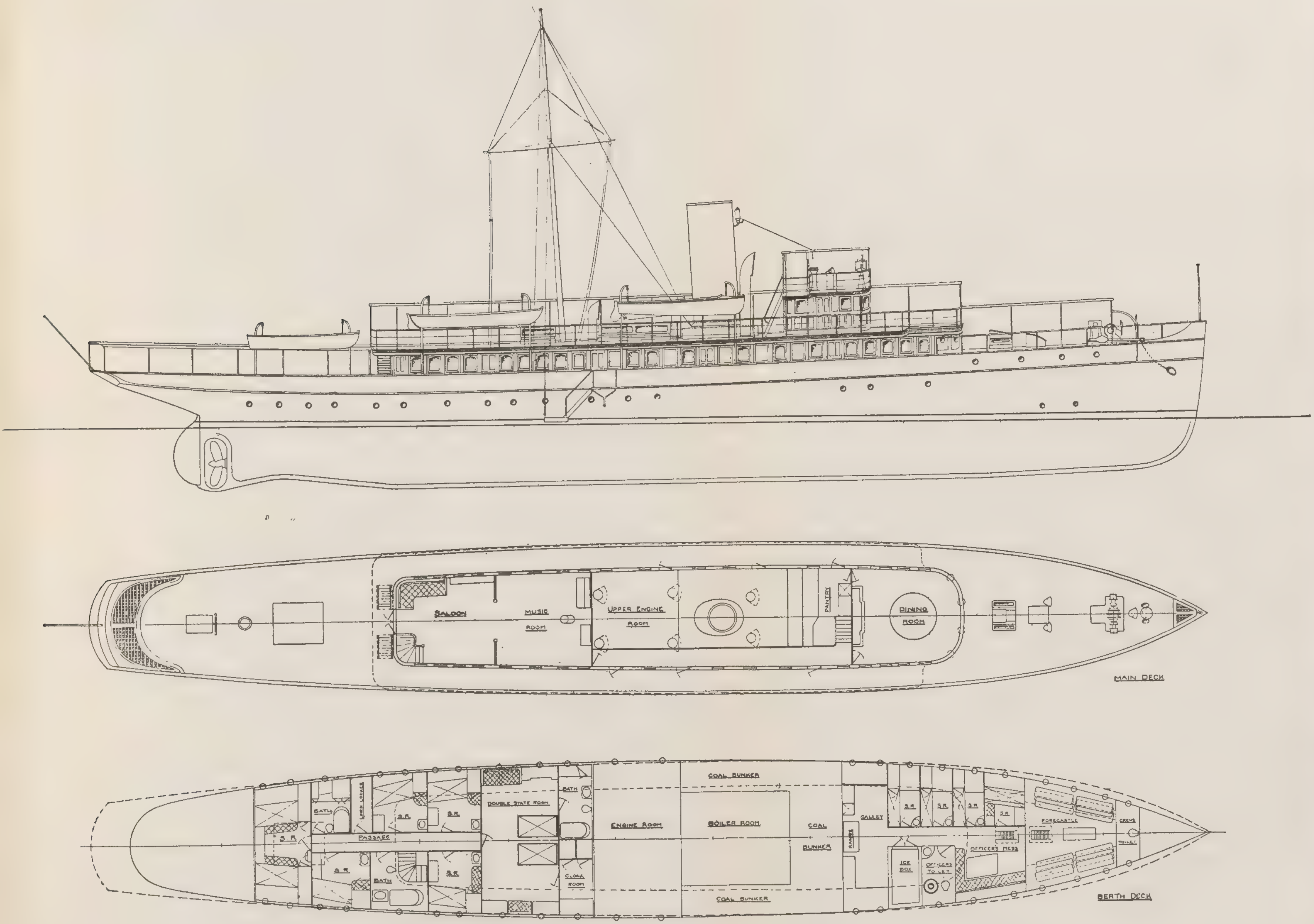
SALOON
MUSIC ROOM
UPPER ENGINE ROOM
PANTRY
DINING ROOM
MAIN DECK
COAL BUNKER
ENGINE ROOM
BOILER ROOM
COAL BUNKER
GALLEY
PASSAGE
DOUBLE STATE ROOM
BATH
S.R.
CLOAK ROOM
ICE BOX
OFFICERS TOILET
OFFICERS MESS
FORECASTLE
CREWS TOILET
BERTH DECK

Fig. 9.

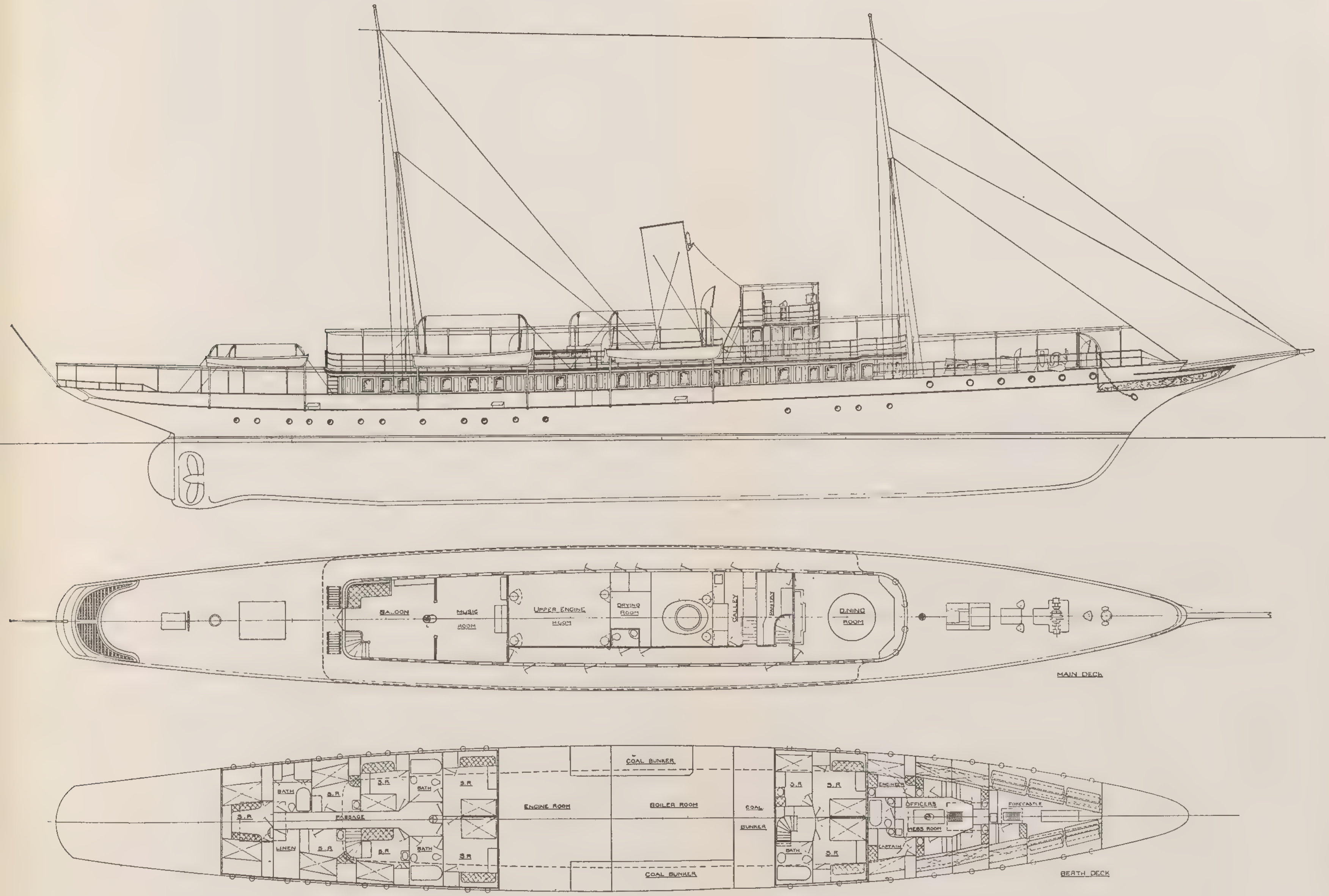
SALOON
MUSIC ROOM
UPPER ENGINE ROOM
DRYING ROOM
GALLEY
PANTRY
DINING ROOM
MAIN DECK
COAL BUNKER
BATH
S.R
PASSAGE
LINEN
ENGINE ROOM
BOILER ROOM
COAL BUNKER
ENGINEERS
OFFICERS
MESS ROOM
CAPTAIN
FORECASTLE
BERTH DECK

Fig. 10.

been adapted to the speed desired. Maximum speed is not now important and seldom exceeds 2 knots over the regular cruising rate. Scotch boilers are very popular for this use, but the heavier type of water-tube is coming into favor. In the smaller boats, the latter has a decided advantage; there is more room for coal and the smaller weight makes a very much better sea-boat. There is no objection to the use of water-tube boilers in this country, as our engineers are all accustomed to their use and have no trouble handling them. The long-stroke, triple-expansion engine, with three or four cylinders, and the Stephenson link gear are customary. The auxiliaries are independent—American practice differing materially from the English in this respect.

What the future may bring forth is hard to tell. One thing is certain, however, that as our wealthy men become more accustomed to yachting, their requirements become more rational and practical, and the sea-going and cruising qualities of the boat become more important than arrangement of accommodation. The designers, thus encouraged and assisted, are sure to advance and improve, and their production, I feel sure, will be a credit both to their country and themselves.

ILLUSTRATIONS.

Steam Yacht.

8. Express Yacht.
9. Modern Coastwise Yacht.
10. Moderate sized Sea-going Cruiser.

MOTOR YACHTS.

The first time naphtha or gasoline was used in this country for marine propulsion was in 1885. In this year, Mr. F. W. Ofeldt brought out the naphtha engine. This engine has three cylinders, surmounted by a tubular boiler or retort. A pump on the shaft forces naphtha to the retort, where vapor is generated. This vapor then goes to the engine and is used expansively. It also goes through an injector to the burner and supplies the fuel. The exhaust gases go to an outside condenser, and from there to the tank. The system is simple and automatic; when once started, there is no necessity for re-adjustment of feed.

At the time these engines came on the market, naphtha was a by-product and was thrown away. Mr. J. A. Bostwick, of the Standard Oil Company, perceiving that here was a possible future for this by-product, assisted in the financing, and in 1886 the Gas Engine & Power Co., of Morris Heights, was formed. They built both the engines and launches; the engines ranging from 1 to 16 horsepower and the launches from 18 to 75 ft. The naphtha boats were successful, so their business grew rapidly. In a period of ten years, over four thousand were supplied by them. The models of the boats differed very little. The keels were straight, the midship section had a moderate deadrise, the water-lines were sharp at both ends, and there was generally an elliptical overhang stern. The smaller boats were open or had a standing roof with curtains, while the larger ones had high cabin houses, often with a raised portion forward for the steersman. The engine was placed very far aft, and the naphtha tank in the extreme bow. These boats were certainly very popular in their day, but are now going out of use, due to the low power and high fuel consumption of the engines.

The four-cycle gas engine, which is the engine of today, was invented by Dr. Otto, in 1876. The first engine, in this country, of this type was built by one of the founders of the Union Gas Engine Co., of San Francisco, in 1884, and was placed in a boat in 1885. This engine was so successful that the Union Gas Engine Co., of San Francisco, was formed. It is interesting to note that this engine was equipped with make-and-break electrical ignition, which is the most reliable type for open boats today.

In 1890, a considerable number of Union engines were in satisfactory operation about San Francisco Bay.

Gottlieb Daimler, who was for a long time Chief Engineer of the Otto and Langdon Works, further developed the Otto engine, and placed his improved engine on the market in Germany, in 1891, at which time he formed the Daimler Motor Co. In the latter part of 1890, the basic patents of Dr. Otto expired in England by limitation, and at the same time were freed in this country.

The Daimler Company, of Steinway, Long Island, was incorporated in 1889. They started to build the German Daimler engine in 1890. The Globe Company, of Philadelphia, was formed, in 1893, to build the Union engine on the east coast. The era of the motor boat may be said to have commenced at this time. The Daimler Company built engines and boats as well. They started with hot-tube ignition. They built up a large business and were at the height of their popularity in 1905. The Union and Globe Companies built engines only. They advanced very rapidly both in output and size, and developed a very prosperous business.

The two-cycle engines probably date nearly, if not quite, as far back as the four-cycle; as Clark Sintz, it has been stated, had a boat running on the Detroit River, with one of these engines, in 1885. Their development, however, has been slow. They have not had a very great influence on the evolution of the modern motor boat, the horsepower and speed being limited. Their use has been in moderate sized boats and commercial craft. For the above purposes, however, thousands have been built, and their usefulness in this field has been so great that it is impossible to estimate it. They are now cheap to build and are very reliable in operation.

Probably the best known name and the most progressive designer of gas engines for motor yachts in this country was the late Carl C. Riotte. To his initiative is largely due the progress that has been made in the last 18 years. Mr. Riotte, associated with his brother, built a number of engines of from 1 to 25 hp. previous to 1898, under the name of Empire. In 1898, they left that company and organized the Standard Motor Manufacturing Company, which is now the Standard Motor Construction Com-

pany. The Standard Company started with the make-and-break electrical ignition. From the beginning, their engines have been noted for their reliability in operation. In 1899, they built engines up to 30 hp., and in 1900, built a 75 hp. engine, having a bore of 9″ and a stroke of 12″. A large number of these engines, with intermediate sizes, followed. In 1903, they built the first six-cylinder engine. This engine was a decided step in advance. It developed 110 hp., and besides having a more perfect balance than four cylinders, was air starting and reversing. These were followed in 1904 with 300 hp. engines of the same type, and in 1906 with 400 and 500 hp. double-acting engines. James Craig followed closely the Standard with engines up to 300 hp., and later on, the Gas Engine & Power Co. and Chas. L. Seabury & Co., Consolidated, did the same. As the engines improved in reliability and efficiency, the demand for motor boats increased. In the same way as the size of the engines increased, so did the size of the boats; the development of the boat depending largely on the engine. The progress of the engine, however, has always remained behind the demand.

The earlier boats followed closely the lines and arrangements of the naphtha launches, but as the engines decreased in weight or increased in power and variety, the field broadened and the boats separated into distinct types. The open boats developed into the high-speed, racing type, or into the runabout or family boat. In the same way, the cabin boats separated into a speed type, with small accommodations, and the slower family cruiser.

The motor speed-boat has had a very interesting development. The model of the earlier ones had a long bow on the water-line, rounding into an elliptical, flat stern, or a V-stern, of the "Normand" type. The forefoot was deep, the keel line ran nearly straight to one third of the length, and then swept up to the water-line at the stern. The engine was placed well forward. These boats ran beautifully but had a tendency to settle bodily, and as the speed increased, to draw down more and more aft. On account of this, the model was gradually changed. The water-line was filled somewhat forward, the forefoot reduced, and the keel line dropped at the after end until it became nearly a straight line. The end of the stern was cut off straight and the

boat was made nearly as wide at that point as amidships. The appearance suggested the fore end of a normal boat cut off just aft of the midship section. The engine was then placed well aft. This made a boat much better in rough water, and one that had more of a tendency to climb out than settle: 33 miles an hour was reached with this form of model.

In 1910, the "Pioneer" came here from England to race for the Harmsworth Cup. This boat was a hydroplane, designed by William H. Fauber, an American, who had originated this form of hydroplane model and had developed it in France. This boat was 40 ft. long, had 350 hp., and attained a speed of 40 miles an hour. The bottom, fore and aft, was a series of inclined steps, the sections being slightly concave; the stern was wide and the bow full. The boat, impelled forward by the high power, rose bodily until the forward third was entirely out of water, and only a part of the steps aft were in contact. This principle was evidently so superior that the attention of designers of racing boats has since then been devoted to this type. From several steps, the number has decreased until now the general practice is to have only one, thus giving two planes for the boat to run on. The section is concave or convex at the step, and flat, with square corners, at the stern. It is confidently expected that 60 miles an hour will be attained this year.

The launches for general use have been mainly of the normal type, having models similar to the early speed boats, but not so extreme. The tendency recently has been to widen the sterns to nearly the maximum width and cut them straight off.

Another type has recently been gaining in favor. This is known as the V-bottom or monoplane. It resembles closely the earlier hydroplane, but is without steps. The sections of the bottom are straight or concave; they have considerable deadrise or angle at the bow, this angle gradually decreasing until the stern is reached, where it is nearly flat. These boats have more stability than the normal type with the same beam, are faster, and are excellent sea-boats.

The cruising or cabin motor-boats are now so numerous that it is rather difficult to describe them. Almost every conceivable form of design has been tried, often with unsatisfactory results. The attraction of a cruising boat, with the accommodations of a

steam yacht of much larger dimensions, that could be run at a moderate expense has led hundreds who have had no boating experience before, to take up this sport. Competition among builders and designers has been very keen; very often, attractive paper designs and alluring prices have secured orders. There are, as a consequence, a large number of boats that have been badly built or badly designed and are practically useless. Fortunately, now, the public is becoming more discriminative and better educated. Many of the unreliable builders have gone out of business, and the really first-class ones are getting the bulk of the work.

The type of boat most popular today, and the one that includes most of the new designs, is the raised-deck cruiser. This boat has a high bow, with a flush deck forward; this runs from one third to one half of the length. Aft, the boat has a cabin-house, with a passageway on each side, the roof of the cabin-house being, as a rule, a continuation of the forward deck. Aft of the cabin-house is a deck running to the stern, generally provided with chairs. This makes a very comfortable place on windy days. On the forward deck is placed the steering wheel and, as a rule, a control for throttling and reversing the engines. One man, in consequence, can handle both boat and engine. This man, together with a steward, is often the entire crew of a good-sized boat. The largest boats of this type have a sunken deck-house forward. This is used as a dining saloon, or dining saloon and main saloon when the after accommodations are given up entirely to staterooms. When a deck-house is used, the steering wheel and controls are placed on a raised platform at its after end.

The interior arrangements of the cruiser type differ with different sized boats and with the individual requirements of the owner. The arrangements in general, however, are divided into two classes. The first has the engines placed very far forward and the fuel tanks aft. Often the engine room, galley and forecastle are all in one. This arrangement puts the owners' quarters amidships, the roomiest part of the boat. It is certainly very convenient and attractive and works very well where the cruising is done in smooth water. The other arrangement is to place the engines and tanks amidships, the owners' quarters aft, and the crews' quarters and galley forward. Where the boat is large

enough, the deck-house has a pantry at the after end; beneath this the galley, and a dumb-waiter connects the two. This arrangement gives less room to the owner, but much better accommodations for the men. Placing the engine and tanks amidships, concentrates the weights fore and aft, and lowers them vertically. This produces a boat very much easier in a sea-way and one having considerably more stability. I consider this the only satisfactory arrangement for use in open waters.

The largest motor boats have either the conventional yacht form or are of the semi-speed type, with the flat stern. These boats are flush decked, with deck-houses forward and aft. They are very roomy, having the accommodations of steam yachts half as large again. They are fairly economical to run, and many have proved themselves excellent sea-boats, although the displacement is much less than a steam yacht of the same size.

The future of the motor boat is hard to tell. It will undoubtedly depend on the question of fuel. During the last three years, gasoline has nearly doubled in price. This has made the running of the high-powered boats much more costly. Up to the present time, very little attention has apparently been paid to the question of engine economy; the efforts being devoted to smoothness and quietness of running, reliability, and outside appearance. An examination of the engines on the market discloses a wide field for improvement. Sharp or right angle turns prevail in inlet and exhaust manifolds, and the inlet manifolds on six-cylinder engines are, with few exceptions, such that an even distribution of gas to each cylinder is impossible. The carburetion is also in its infancy, and there is a wide field for improvement here. Hot air from the crank pit is generally used to heat the vapor, instead of the proper water-jacketing of manifolds—single- instead of multiple-jet carburetors, except by the Standard Company for large engines, are used, and air valves act so as never to really give the proper mixture. The exhaust is also a matter for consideration. There is a possibility that by means of a well-designed exhaust manifold, back pressure may not only be eliminated, but a slight vacuum obtained. As necessity is the mother of invention, the high price of gasoline is sure to force our engine builders to give these questions thorough investigation.

The advent of the Diesel engine, with its low fuel cost and great economy, will also have its influence. This engine has just made its appearance in motor boating. We have one boat, the "Aeldgytha", that went through the season of 1914, cruising some 4,000 miles, without a hitch or set back of any kind. These engines are American in design and are original. They were the work of James Craig, the well known gas-engine builder, and while they were the first ones he has attempted, have turned out a great success. While gasoline was 8 cts. per gallon, the Diesel engine was not so attractive, as the high first cost of the engine offset the low cost of fuel. But as the cost of gasoline goes up, the comparative economical value of the Diesel will improve, so that possibly before long the Diesel will supersede the gasoline engine, especially for large-powered cruising boats; the question of safety and radius adding further to their attractiveness.

ILLUSTRATIONS.

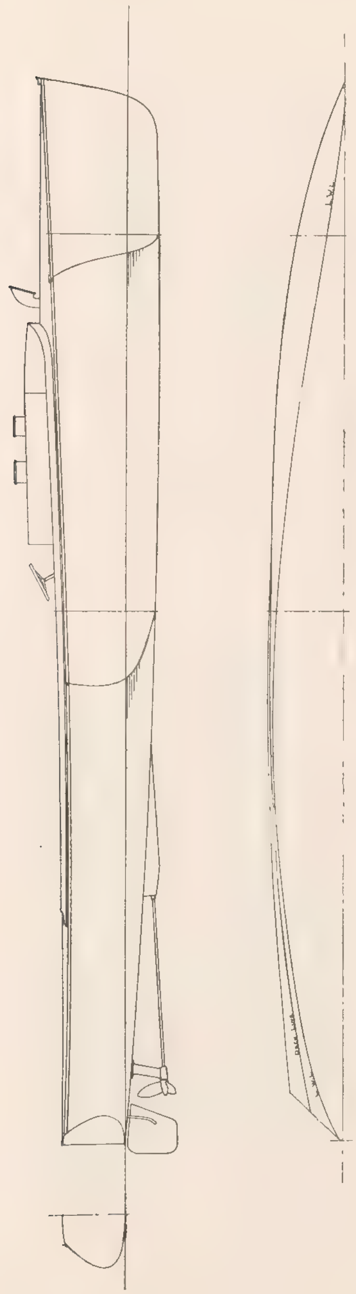

Fig. 11.

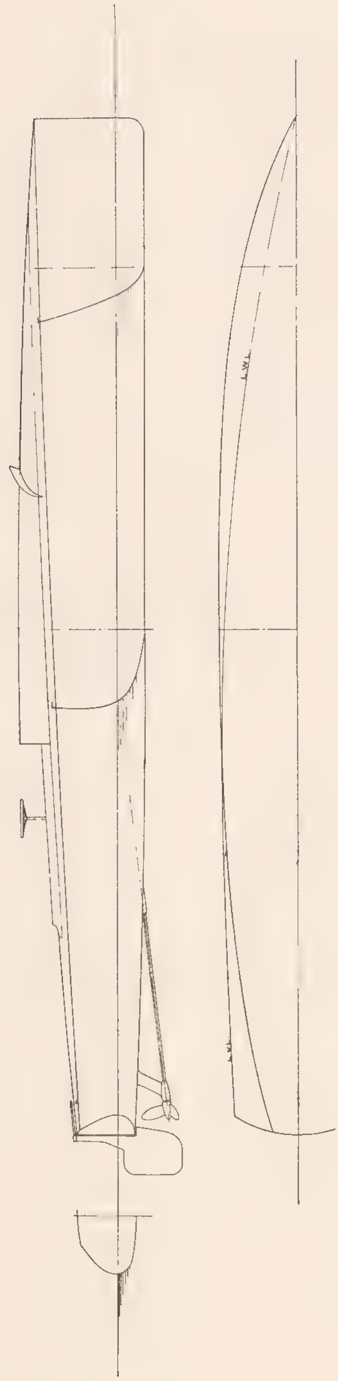

Fig. 12.

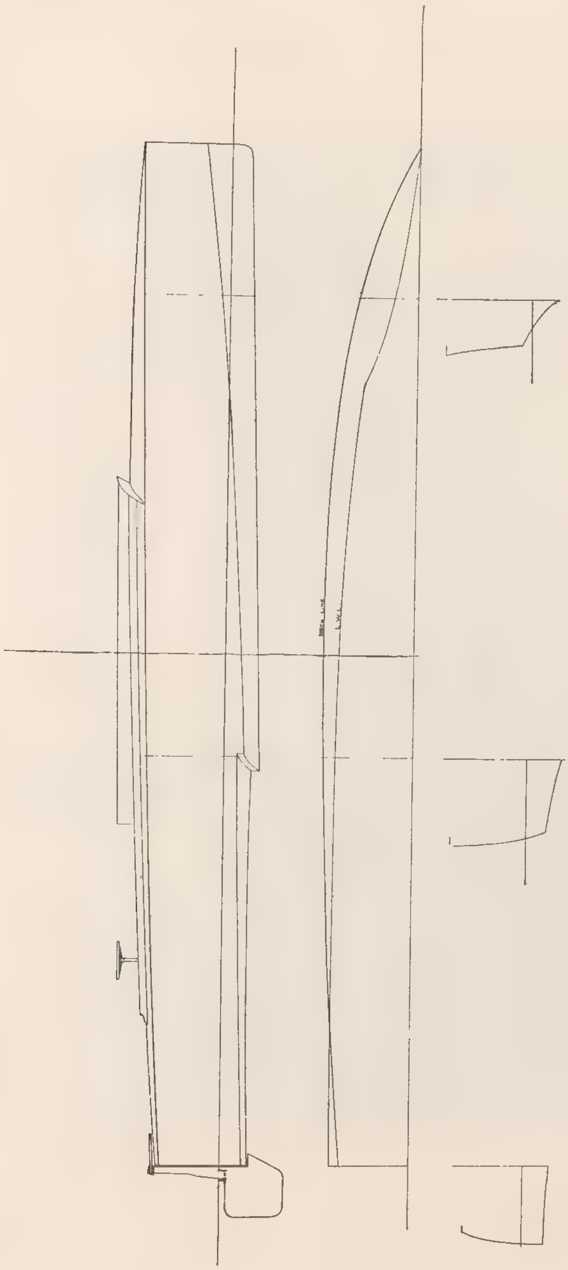

Fig. 13.

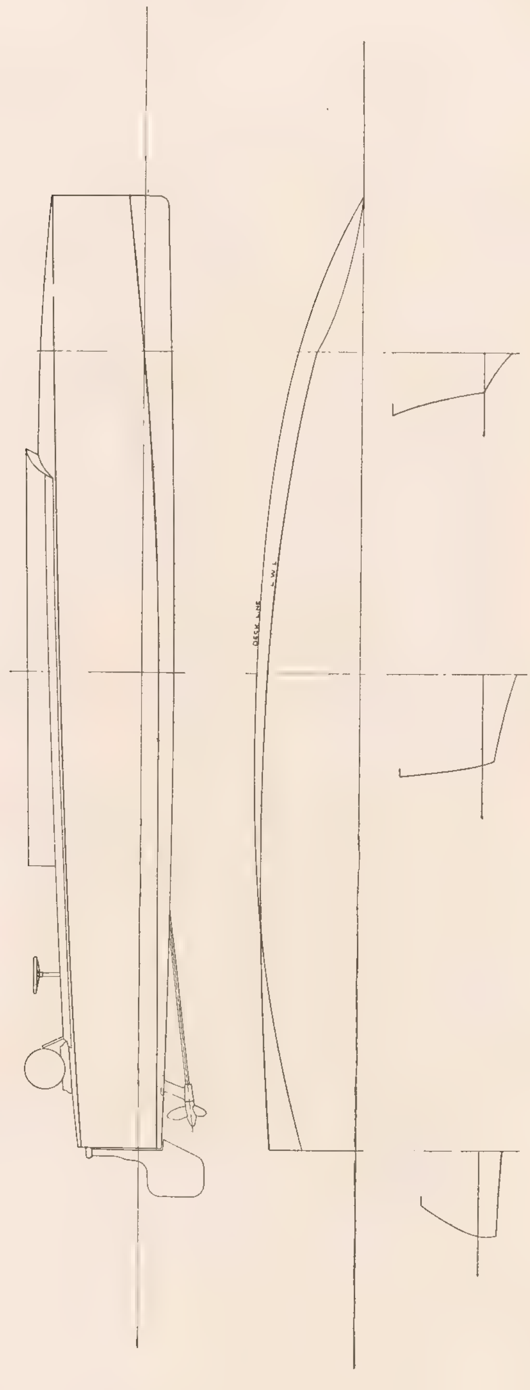

Fig. 14.

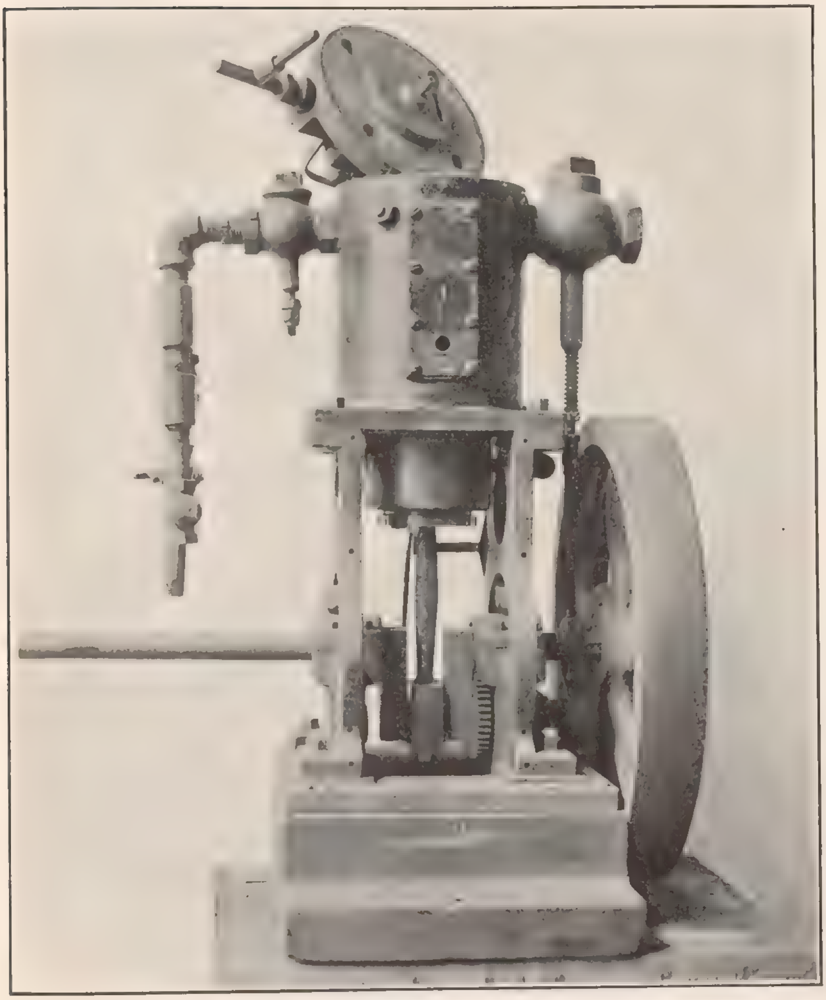

Fig. 15.

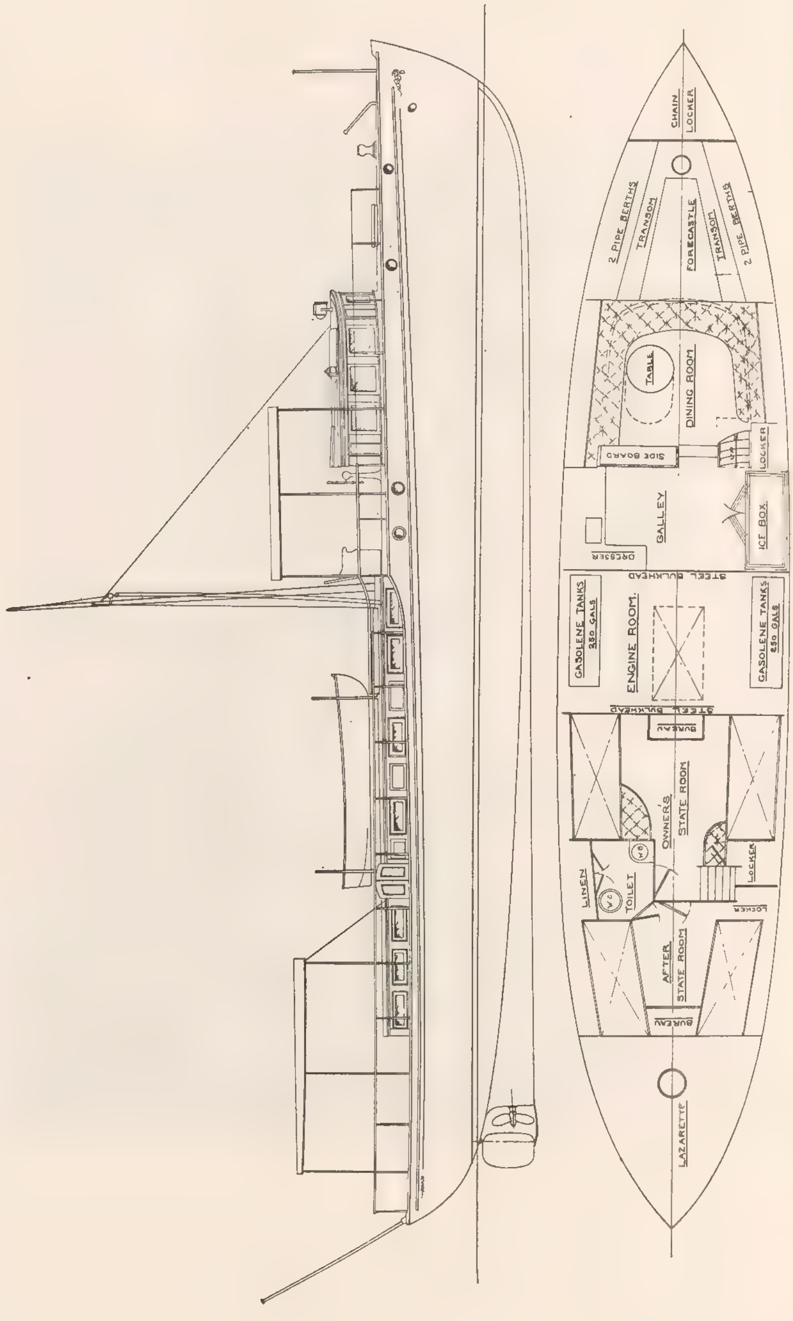
CHAIN LOCKER
2 PIPE BERTHS
TRANSOM
FORECASTLE
TRANSOM
2 PIPE BERTHS
TABLE
DINING ROOM
SIDE BOARD
LOCKER
DRESSER
GALLEY
ICE BOX
STEEL BULKHEAD
GASOLENE TANKS 250 GALS
ENGINE ROOM.
GASOLENE TANKS 250 GALS
STEEL BULKHEAD
BUREAU
OWNER'S STATE ROOM
LINEN
TOILET
LOCKER
LOCKER
AFTER STATE ROOM
BUREAU
LAZARETTE

Fig. 16.

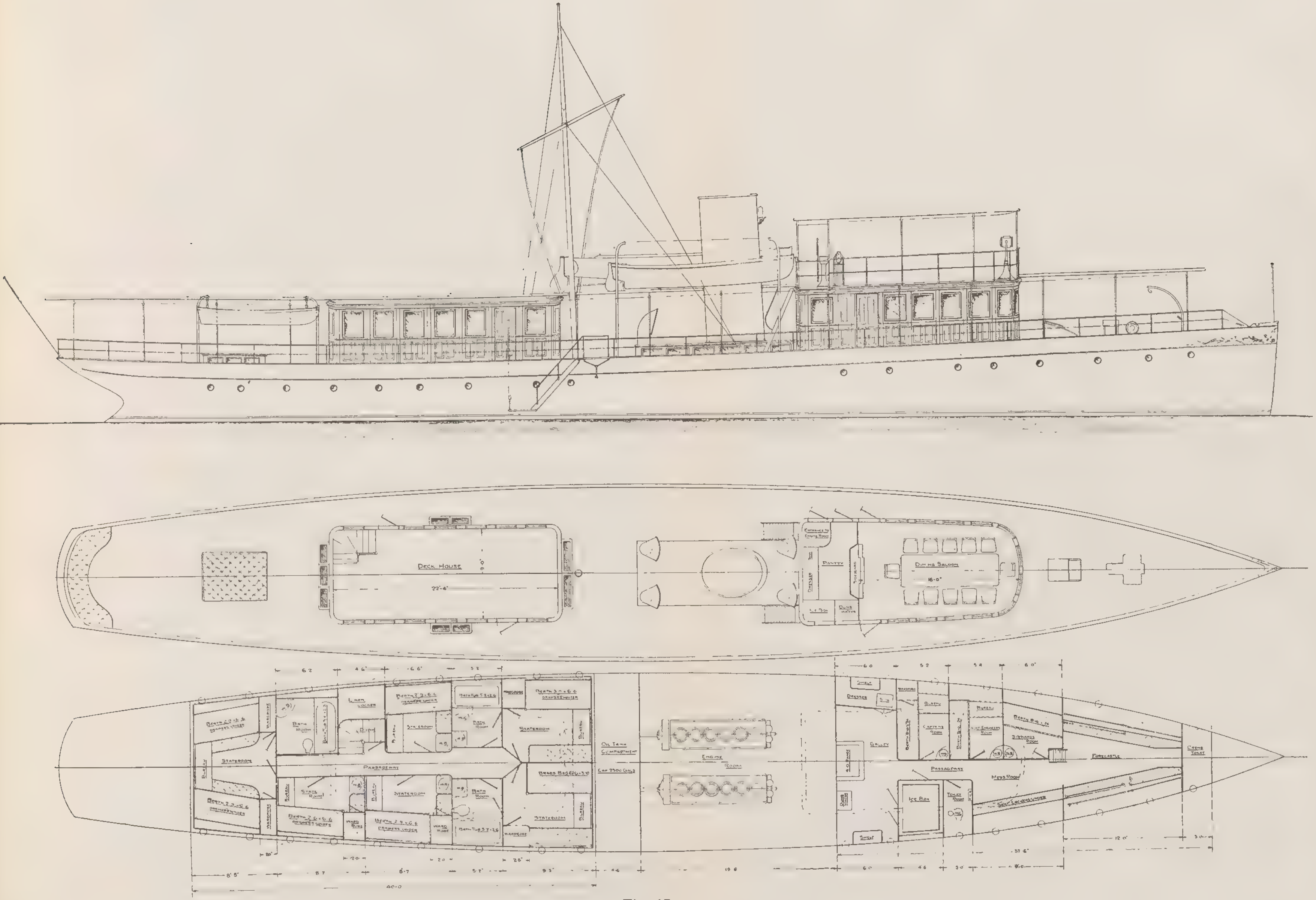
Deck House
Dining Saloon
Pantry
Stateroom
Passageway
Engine
Room
Galley
Forecastle
Ice Box

Fig. 17.

Paper No. 203

THE UNITED STATES LIGHTVESSELS, Nos. 101 AND 102.

By

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The lightvessel, as an aid to navigation, represents a specialised type of marine construction and involves many problems of interest to the naval architect and shipbuilder.

On the occasion of the International Engineering Congress, it seems appropriate to present to the members interested in this field of work a brief description of recent vessels of this type, in order to mark the characteristic features of such construction at the present time.

The duplicate second-class Lightvessels Nos. 101 and 102, now under construction for the U. S. Service, may be taken as illustrative of the development of this type in the United States, in all but the matter of size. The displacement is but 360 tons, while that for a vessel of the first class is 660 tons.

These vessels were designed in the Division of Marine Engineering, U. S. Bureau of Lighthouses, and have the following general dimensions and characteristics:

Length over all	101 ft. 10 in.
Length on designed water line	92 ft. 3 in.
Beam molded	25 ft. 0 in.
Depth of hold from top of main deck beam to top of keel amidships	12 ft. 2 in.

Displacement (molded)—11 feet 4 inches draught in salt water—360 tons.

Signal light—Six panel flashing and fixed lenses.
Elevation above water—50 ft.
Candle power of flash—24,000.

Fog signal—Compressed-air siren.
Siren—6 inch.
Hand bell—700 pounds.

The lines of the vessel, Plate V, are the development of many years' observation on the performance of these small vessels as signal light platforms when moored at sea. The character of the body plan is such that the wedges of immersion and emersion in transverse rolling are nearly equal and the usual impulse of excess buoyancy is thereby avoided. Fore and aft, the lines are full, and experience seems to warrant the practice, although the argument might be offered that a vessel with finer ends would lift less quickly on a passing wave. The feeling among seamen, however, appears to be against a vessel which might be frequently awash in heavy weather. Further details of the form characteristics are shown on Plate VI, by the curves of displacements, centers of buoyancy, metacenters, centers of gravity with varying conditions of load, etc.

The vessel is constructed throughout of steel and other fireproof materials, with the conventional structural elements as shown on the midship section, Plate IV. The scantling throughout is much heavier than that required by any classification society for a vessel of the size, in order that the greatest practical strength may be obtained, as well as sufficient material to bear the heavy corrosion brought upon a vessel liable to extended periods of continuous duty in exposed waters.

The arrangement of the hull, as shown in Plates II and III of the inboard profile and decks, is that of a continuous upper deck vessel, subdivided below the main deck, by watertight bulkheads, into six general divisions. The first of these is subdivided horizontally to form a trimming tank and store for paints, oils, and articles of a similar nature; the second compartment contains the chain locker and general store rooms; aft of this compartment, extending entirely across the vessel and subdivided by a watertight flat, are the structural fresh water tanks and illuminating-oil case storage; the next compartment, which is carried to the main deck, contains two fuel-oil tanks; two more integral bulkheads form a machinery room with wing coal bunkers; and aft of this compartment the vessel is further subdivided on the line of the lower deck to give an after trimming tank and lower-deck storage rooms.

The entire forward section of the main deck is given to the anchor-handling gear, which is of absolute importance in a ves-

sel of this class. It consists of an enclosed breakwater, into which the main central hawse pipe of the mooring anchor and that for the reserve anchor and chains open, and which drains back through the pipe itself.

Immediately aft of the breakwater are two plate foundations carrying the chain compressors and springs, from which the chains lead directly to a large double steam-windlass. The crews' quarters are separated from the windlass space by light divisional bulkheads, and consist of staterooms for the men, galley, pantry, toilet, bath, and mess room. The gangways abreast the machinery room casing are fitted with work benches, tool lockers, etc. The quarters for the officers occupy the after portion of the main deck of the vessel. The master and chief engineer have staterooms of considerable size, each fitted with desk, locker, wash basin, etc., while those of junior officers are nearly as complete. A pantry, mess room, bath and toilet complete this section of deck. The vessel is heated by steam throughout, and hot and cold running water supplied to the galley, bathrooms, and all officers' staterooms.

The upper deck forward is fitted with an anchor crane and storage for the reserve anchor. A small deck-house at the foot of the mast supports the bridge and is fitted as a chart and watch room. The deck trunk, extending aft, supports the stack and siren tower, and forms the companion to the officers' quarters.

The outboard of the vessel is shown in Plate I. The chief characteristic and distinguishing mark, aside from the usual sheer, freeboard, and rounded gunwale, lies in the steel tubular foremast, which carries a cylindrical lantern at its head for the protection of the signal light. A small main-mast is fitted, and the vessel is rigged for two storm sails.

The main propelling power consists of a 200-horsepower, four-cylinder, reversible, internal-combustion engine, using oil exclusively as fuel, and driving a single four-bladed propeller. The auxiliaries, including the windlass, bilge and sanitary pump, etc., are operated by compressed air.

The moorings consist of two 5000-pound mushroom anchors, and 120 fathoms of 1⅝ inch stud-link chain. The anchor for regular service is carried in the central hawse pipe, and the other

in steel brackets at the upper deck. A 500-pound kedge anchor of the stockless type is stowed forward of the pilot house.

The illuminant is kerosene oil. The lamp consists of a reservoir of kerosene under a pressure of about 60 pounds, which ejects the oil through a heating tube, where it is vaporized and from which it is thrown as a vapor upon a mantle which becomes incandescent under the heat of the flame.

The signal lighting apparatus consists of one 500-millimeter diameter lens with six flashing panels. The lens is mounted upon a fixed table-plate in the lantern, and revolved by clockwork driven by weights traversing the mast. The characteristic is not yet determined, but will, of course, be made up of some factor of the six-panel flash. One of these vessels is intended for general relief service, and its lens is therefore constructed with demountable panels which can readily be removed and replaced by others giving a fixed light.

The fog signal consists of a 6-inch mechanical siren, with horn operated by compressed air. The air-compressing units are in duplicate and each of sufficient capacity to deliver 200 cubic feet of free air per minute at a pressure of 90 pounds. The compressors are of the vertical type, and are driven by vertical internal-combustion engines of approximately 40 horsepower. The rotor of the siren is driven by gearing from either compressor engine. Air is delivered to the siren from storage tanks through a reducing valve set at 40 pounds, and the characteristic valve, operated by a clock mechanism, is driven by compressed air at 50 pounds.

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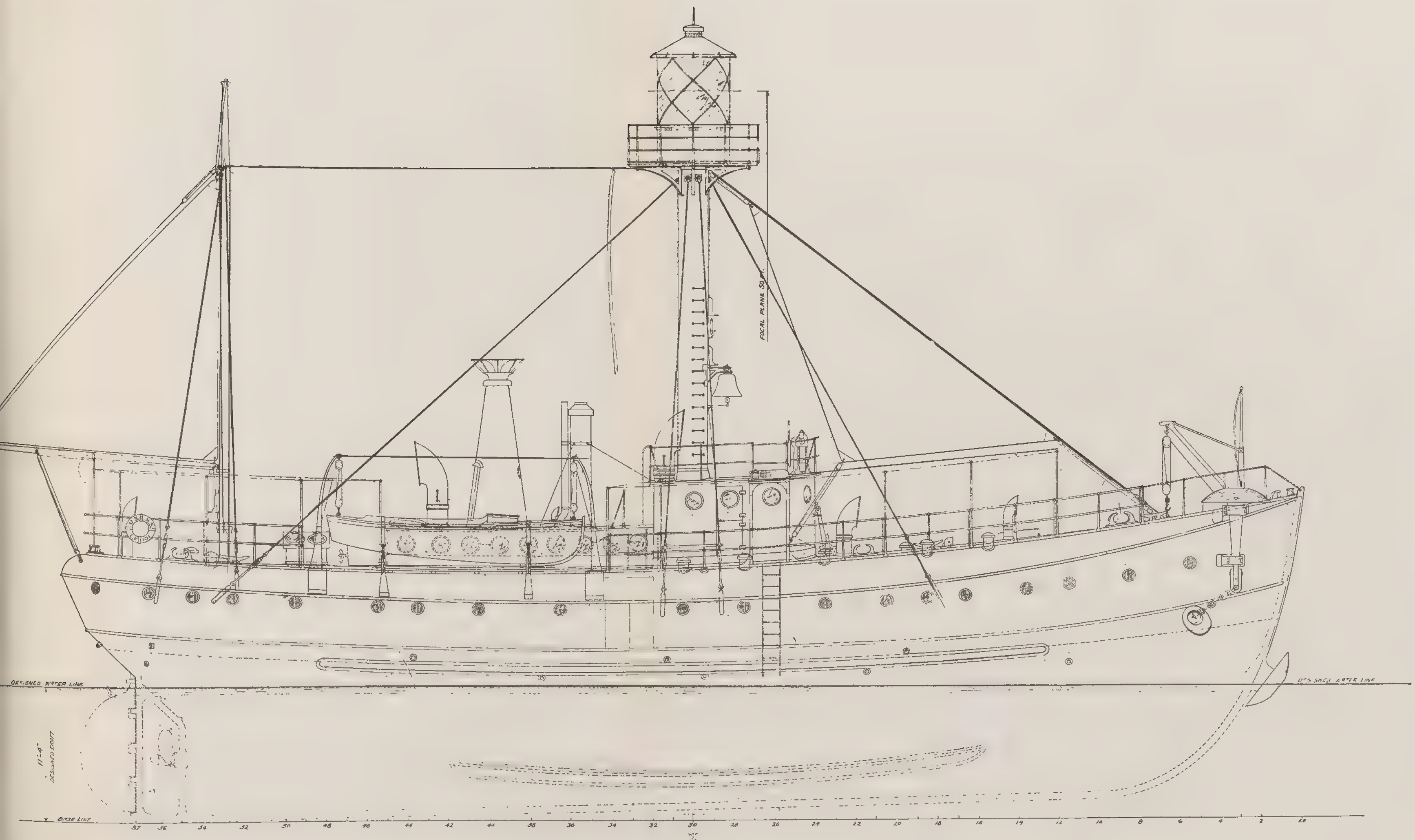

Plate I. U. S. Lightvessels Nos. 101 and 102. Outboard Profile.

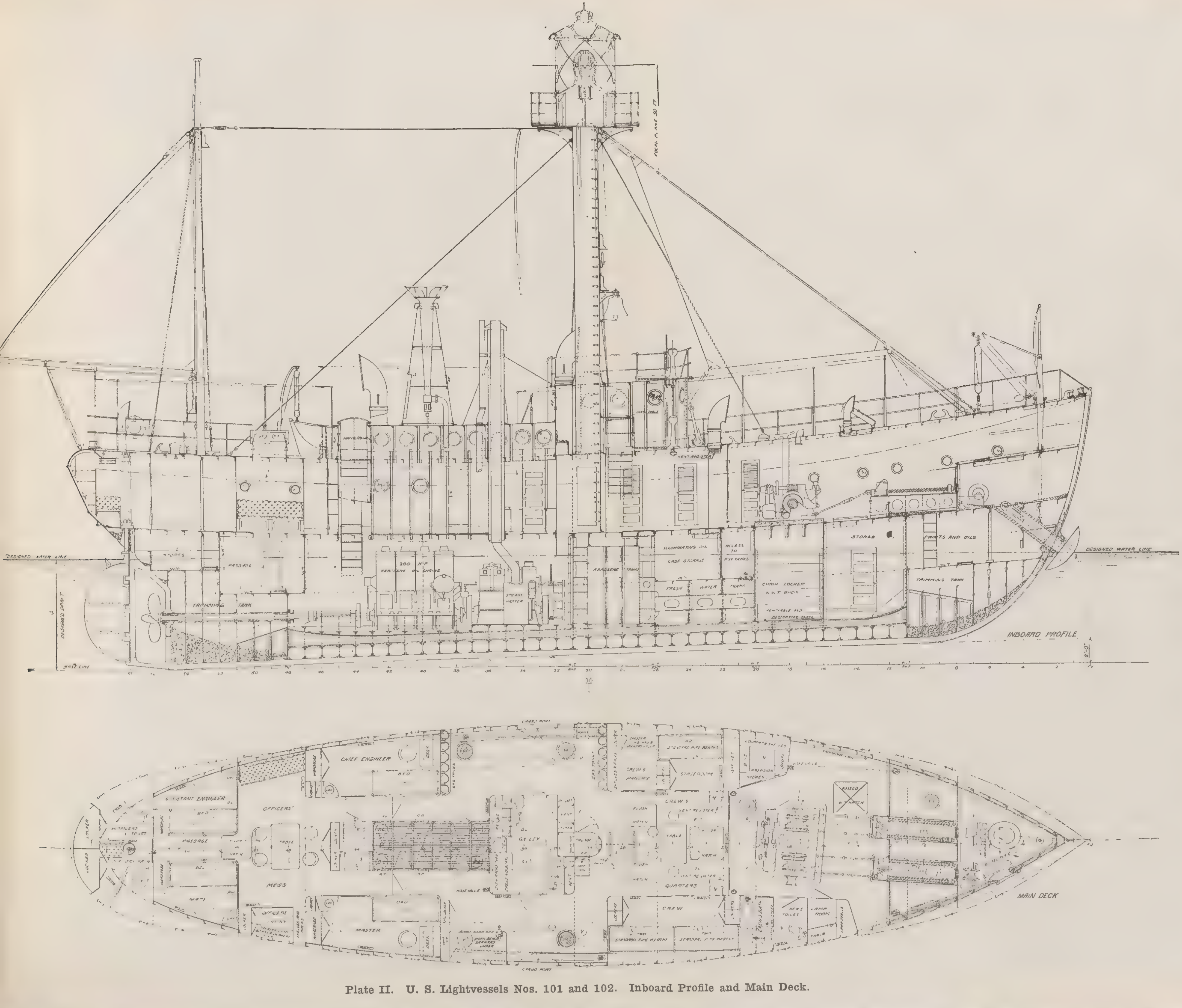

Plate II. U. S. Lightvessels Nos. 101 and 102. Inboard Profile and Main Deck.

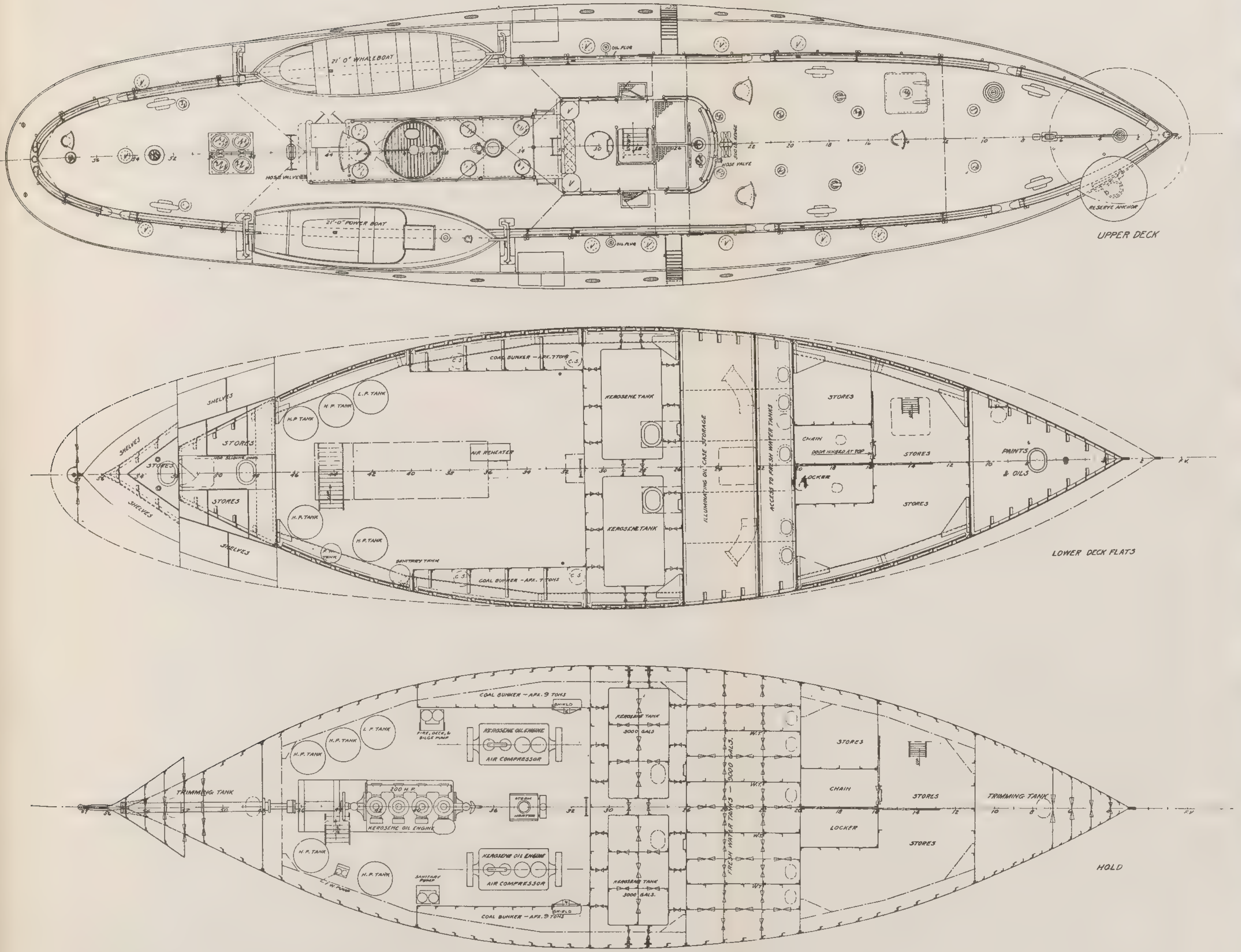

Plate III. U. S. Lightvessels Nos. 101 and 102. Upper Deck, Flats and Hold.

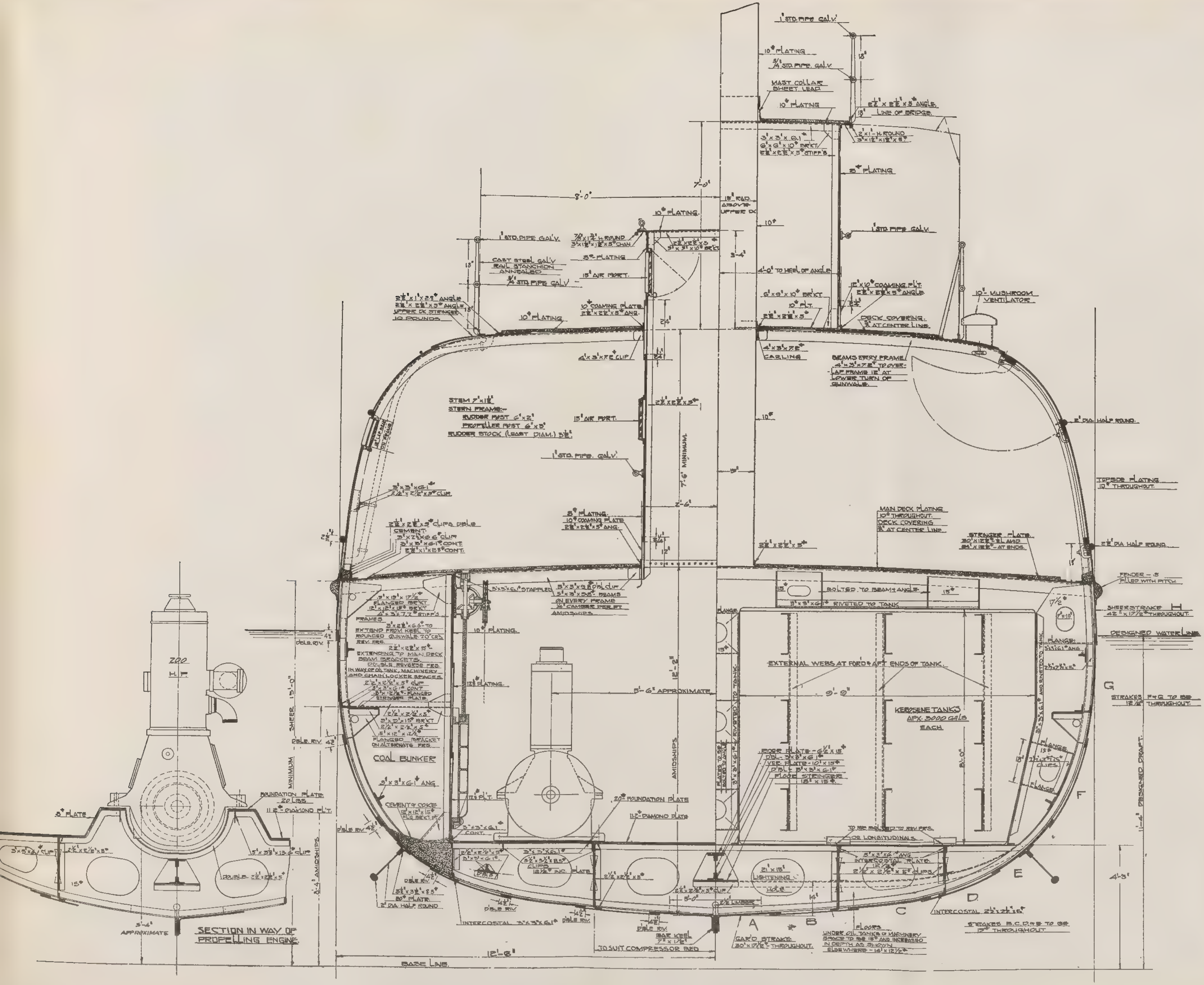

Plate IV. U. S. Lightvessels Nos. 101 and 102. Type Sections.

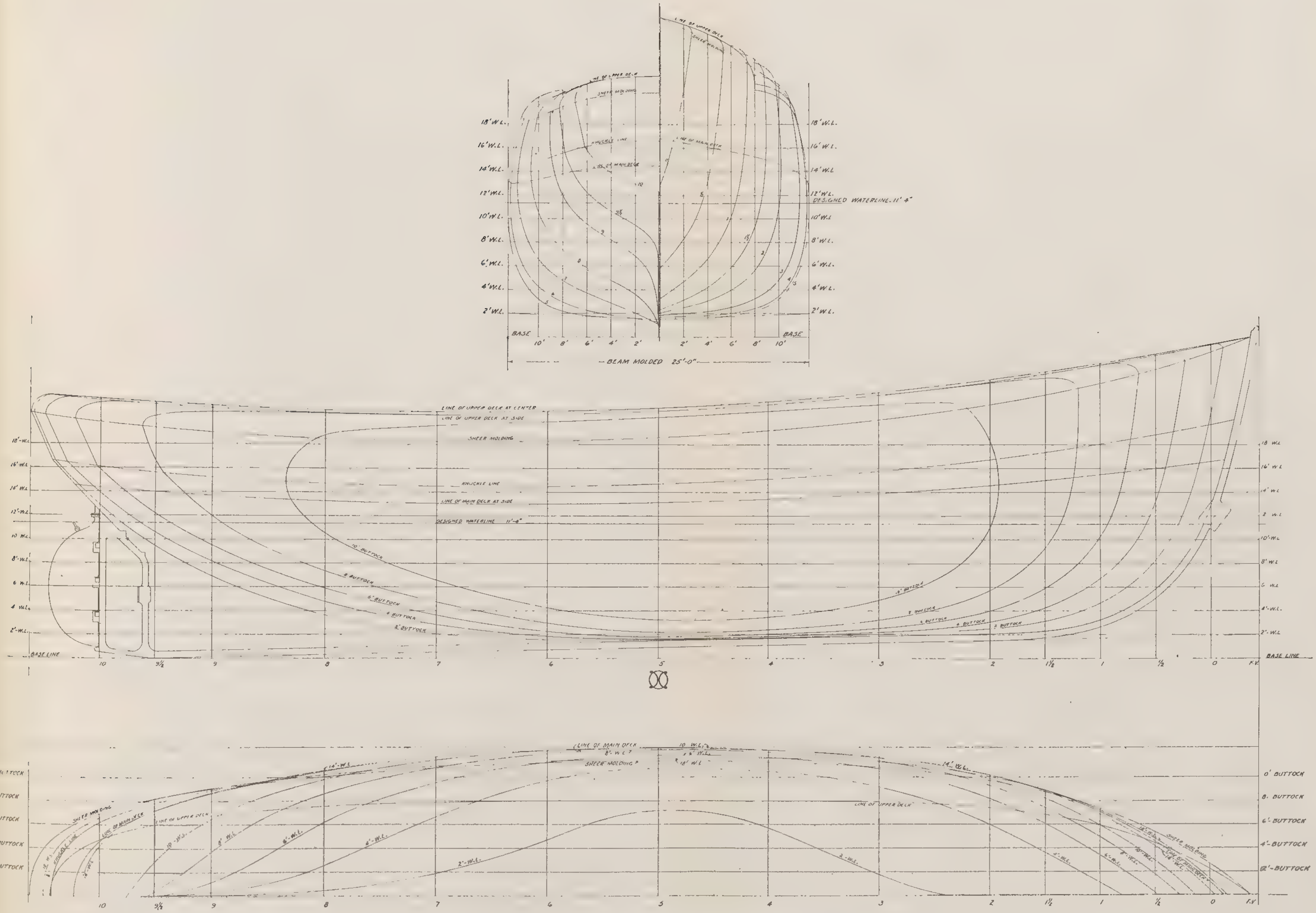

Plate V. U. S. Lightvessels Nos. 101 and 102. Sheer, Half-Breadth and Body Plan.

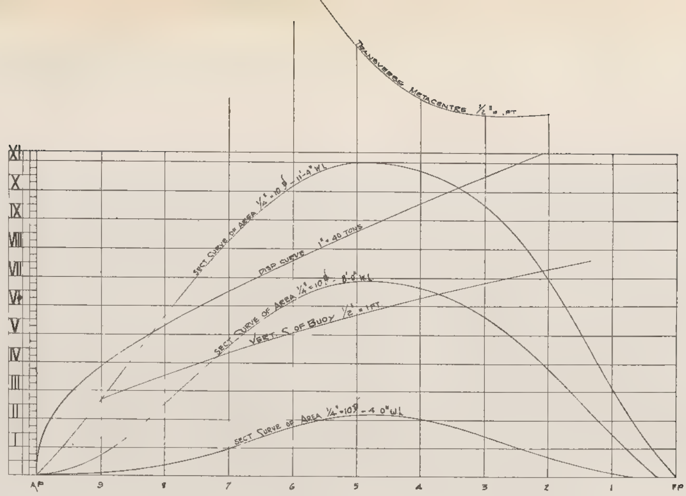

Plate VI-a. U. S. Lightvessels Nos. 101 and 102. Curves of Form.

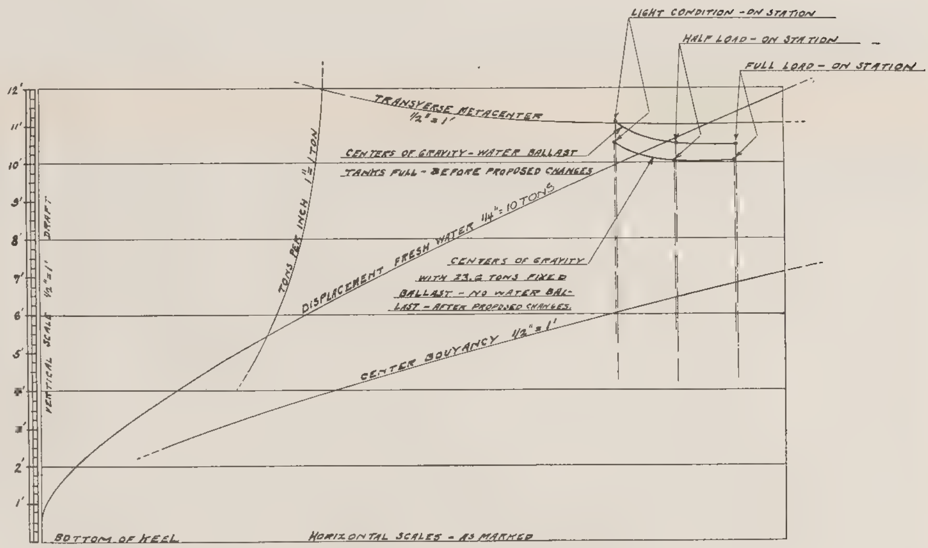

Plate VI-b. Displacement and Other Curves, Including Curves Showing the Movement of the Center of Gravity of the Vessel Between the Light and Full Loaded Conditions on Station.

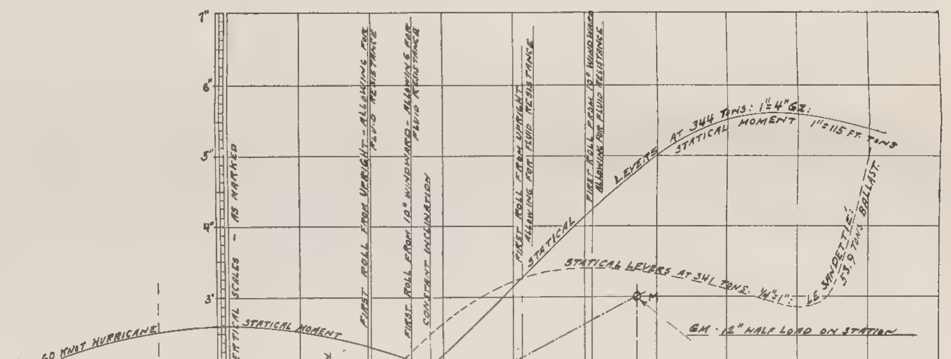

Plate VI-c. Statical Stability Curve for 344 tons Displacement (Half Load on Station) Showing Inclination Due to Various Wind Pressures and Curve of Le Sandettie for Comparison.

trated by half-tone plate of vessel. Reprinted from the Acetylene Journal.

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Paper No. 204

WARSHIPS OF THE FIRST LINE OF BATTLE.

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GENERALITIES.

When, a few years ago, all the leading navies of the world began to turn, for their great ships of the line, to the example of England, and following the lessons of the Russo-Japanese war, to the type denominated "Dreadnought" (from the name of its first example), naval establishments in general comprised an almost infinite variety of types of ships, which included, one may say, the entire series of displacements, of speeds and of gun armament, as well as all possible combinations of the items of defensive armament, from the simple underwater deck more or less protected, to external plating with armor in varying thickness and with varying extension above or below the water line, with or without transverse armor for protection against raking fire, with decks internal and external, more or less strongly protected, etc., etc.

From the beginning of the era of the "Dreadnought" there has been evident a marked tendency to rearrange and to reduce the number of types of genuine ships of war, regrouping them essentially in the four following classes:

(a) Ships of the line.
(b) Cruisers.
(c) Scouts.
(d) Torpedo boats (floating and submarines).

Omitting all present reference to scouts and to destroyers and submarines, this brief paper will be restricted to the evolution, during the past ten years, in warships of the line and in the cruiser type, in order the better to arrive at a more detailed examination of the great modern fighting unit which

seems to arise from the fusion or rather from the reciprocal influence of these two last types of ship.

The search for the greatest military power to be concentrated in a single fighting unit has given rise, during the last ten years, to a continuous increase in size which shows as yet no indication of approaching a limit, but which gives ground for the conclusion that we are already not far from the limit accepted throughout the world in regard to the capacity of harbors, docks, and repair yards, to say nothing of the manageability of the ships themselves.

It is sufficiently characteristic to note the manner in which the greatest navies have been surpassed in the giddy race toward the ideal of the "invincible ship", by certain navies of secondary importance; but evidently the greatest boldness in the introduction of innovations is not always a safe indication of real progress along the path of true development, and in effect there is usually found in the great fighting units of the smaller navies some lack of general harmony of design and in the just balance of the fundamental offensive and defensive characteristics which are to be considered as indispensable for the realization of the maximum military efficiency which it may be possible to realize in the moment of actual need.

II. GUN ARMAMENT.

In warships of the line of the last decade, the caliber of the principal gun armament has continuously increased from approximately 300 to 400 mm. (12 to 16 inches) while the gradual and continuous improvement of the arm has brought successive increase of length in relation to caliber, increase in initial velocity and weight of projectile, increase in weight of charge, in range and perforation, improvement in fire control, greater rapidity and security in loading, increase in length of life of gun, etc. In certain navies, designers have halted for the moment at a caliber intermediate between the 300 and 400 mm. (12 to 16 inches) but it must be realized that sooner or later they must finish by allowing themselves to be carried along to the adoption of the maximum caliber accepted, since no matter what theoretical arguments be advanced, it will always be found in practice that the maximum destructive

effect is always found with a gun of the maximum caliber and the longest range, as has been shown by certain of the most recent naval battles.

With the increase in caliber there has gone hand in hand an increase in the number of guns in each emplacement and in each ship. In the more recent units there are examples of emplacements with 2, 3, and 4 guns, while the number of emplacements varies from 3 to 7 for guns of the same caliber and on the same ship. With a caliber of about 350 mm. (13 to 14 inches), 12 guns per ship have been installed and 16 may be predicted in the near future. With a caliber of about 380 mm. (15 inches) the number of guns per ship up to the present time is about 8 with a clear tendency toward increase.

By consensus of opinion, which has gradually become unanimous, the emplacements of the heaviest guns are all located along the central fore and aft line of the ship. The disposition generally preferred is that of the American "Michigan" with the pairs of superimposed turrets disposed toward the two extremities of the ship. The fire fore and aft has generally been maintained equal in chase and in retreat, with a power corresponding to one third or even to one half of the total armament.

The secondary gun armament of the modern ship of the line has followed a development approximately similar to that of the principal armament, and from guns of 76 mm. caliber (3 inches) of the original "Dreadnought", designers have gradually increased to 152 mm. (6 inches) in the more recent ships, while already in certain cases there are evidences of a tendency toward further increase in caliber. These guns have, in most cases, been placed in fixed casemates, with their fire available fore and aft, preferably intensified in the forward sector, and intended to serve chiefly for defence by day against the attacks of the larger destroyers or submarines, or in case of need against those of scouts. There are not lacking, however, examples of secondary guns mounted in revolving turrets.

The gun armament, principal and secondary, has been, in all navies and in recent times, supplemented with a large number of light guns [of caliber not greater than 100 mm. (4 inches)] with high angle fire and with disappearing mounts. These guns, with the highest facility of manipulation and with

the greatest rapidity of fire, have resulted as a necessity in consequence of the heavy caliber reached by the secondary armament, and in order to give special facility for defense against the dangers which may result from ordinary torpedo boats, especially at night, or from air ships or from submarines; a type of defense for which guns of 152 mm. caliber (6 inches) and larger have shown themselves of unmanageable weight and of disproportionate power.

III. ARMOR.

The development of armor for battleships of the line has followed, during the past 10 years, along lines closely similar to those for gun armament of which it is the immediate and inevitable consequence. Armor plate, on board ship, in the same manner as the guns, has undergone continuous improvement in quality, increase in thickness and hence of resisting power, multiplication in number of plates, and in size, extension of general use, all in such manner as to protect more effectively an ever increasing fraction of the sides and decks of the great battle units, notwithstanding the resultant ever increasing percentage of displacement thereby required.

The vertical external armor has not in all cases been extended from one end of the ship to the other, and in many cases it is found limited to the central part of the ship. Also in its height above as well as depth below the load water line, wide diversity of practice is to be noted in the same manner as wide differences are to be found in thickness in going from the median zone of the belt armor toward the bow or the stern or toward the upper or lower edges. The concept generally followed in order to guarantee to the ship relative security against gun fire, proportioned, so to speak, to the total damage which the loss of invulnerability might occasion according to the zones supposed to be pierced, has led to the development of many different solutions in the determination of the characteristics of the defensive armament of the great ships of the line, because designers for different navies hold widely divergent views regarding the relative significance of damage by gun fire, regarding the protective efficiency of varying thickness of armor, regarding the convenience or otherwise of the use of plates rela-

tively thin, regarding the percentage of effective hits by the enemy's guns of the various calibers and at the most probable ranges and finally regarding the destructive effect of the various types of offensive armament on either the armored parts of the ship, or on those only lightly armored or entirely unarmored.

This complex of discordant views, reacting inevitably upon each other, in conjunction with the excessive weight required for the effective armor protection of a great warship, both from the view-point of cost and of effect on the displacement, has acted as a brake on the ascending path of gradual improvement in the defensive armament of warships, allowing it to be surpassed, if momentarily, by the progress in gun armament. But it may nevertheless be stated that since the days of the original "Dreadnought" the following principles have been accepted by leading naval designers regarding the criteria of defensive armament.

(a) Prolongation of the belt armor to the entire length of the ship, save at the stern where certain navies omit all protection in the vertical plane.

(b) Depth of armor carried to about 2.5 meters (8.2 feet) below the load water line, thus reaching somewhat below the lower limit at the outboard edge of the protective underwater deck.

(c) Extension of the side armor, with few exceptions, to the citadel containing the secondary battery and a greater height of armor belt forward in comparison with that aft.

(d) Thickness of armor maintained constant for a considerable fraction of the protected area in order to secure, with the cooperation of transverse bulkheads armored against raking fire, the defence of all those parts of the ship which may rationally be considered as vital.

(e) Maximum thickness of vertical armor increased gradually from 250 to 350 mm. (10 to 14 inches) and pushed in some ships even to 450 mm. (17.7 inches) for the frontal plates of the turrets for the heavy guns.

(f) Minimum thickness of the vertical armor not reduced below 150 mm. (6 inches).

(g) Continuously increasing importance attributed to the value of horizontal defence, and to the necessity of efficient protection for the various decks, and in particular the upper decks.

(h) The most carefully designed protection in order to secure as nearly as possible the absolute invulnerability of the conning tower.

Many questions, also of a general character, and relating to the armor protection of ships still remain undetermined and not infrequently give rise to discussions of great value among technicians of unquestioned competence, but reaching diverse conclusions among themselves.

Having given a certain ship, perfectly definite in her general lines and as to her displacement, and having given a certain weight disposable for armor, it is in reality very difficult to determine the best mode of utilizing such weight in order to realize the maximum possible measure of defence for the ship itself—whether this will be realized by covering a certain area with plates of a certain thickness, or a greater area with armor a little thinner or a lesser area with armor a little thicker; to which zones of the external surface of the ship should correspond the varying thicknesses chosen; what portion of the total disposable weight should be reserved for horizontal defence of decks; what portion to defence against raking fire; what portion to the smoke stacks; what portion to the defence of conning towers and fire control stations, etc.

It nevertheless remains a noteworthy fact that, independent of the fervor of the discussions which have centered during the last decade about this most important problem, and which, according as one theory or another has led naval designers to favor one arrangement or another, nevertheless the various great fighting units of the leading navies have shown a distribution of defensive armament ever more complete and effective by way of increase of thickness or extent of armored surface, but in all and in absolute value, not sufficient to counterbalance effectively the enormous growth during the same time in the power and number of heavy guns.

IV. UNDERWATER DEFENCE.

Considering the important question of underwater dangers (mines and torpedoes) it is of the highest interest to note, even to the most recent times, the enormous, one may even say inconceivable, disproportion between the high efficiency of offensive armament, likewise under continuous and rapid improvement, and the provisions for defence, sadly deficient, and almost stationary in character. While the destructive effect of mines and torpedoes has become continuously more marked, while the means for firing torpedoes have been continuously improved in power and in precision with corresponding increase in the military value of such means of attack, while there has begun to appear sinister means of offence partaking of the characteristics of the torpedo and of the cannon, while there has been continuous and rapid advance in the submarine and in the terrible effects realized by its use in the present European War, leading to the thought of the eventual suppression of the great floating battleship as a not impossible consequence of the natural law of the survival of the fittest; with all this, one fails to readily understand why no serious and effective provision has thus far been developed capable of securing a high degree of safety against the effects of subaqueous explosion.

In the last decade, notwithstanding the indications of recent naval battles in which underwater dangers have shown themselves to be of the most noteworthy significance, designers have not reached any practical conclusion in regard to the best means to oppose such serious dangers and which may menace the integrity of the floating structure.

It is of course understood that the internal structure of a ship, with special reference to underwater defense, may be easily kept a secret, and that every navy which carries out such studies and experiments has the greatest interest in not allowing the results to pass into the hands of others; but it is believed to be not far from the truth to affirm that although many and important investigations have been carried on by various maritime powers regarding different systems of protection, these have led, nevertheless, to no definite result, to no exhaustive conclusion, unless perchance that the problem of an efficient underwater defence against the most powerful modern arms

must be classed among those of the very highest difficulty, if indeed not impossible of a satisfactory practical solution, or only perhaps through a radical transformation in the disposition of the fundamental constructive features of the modern ship of war.

The principal cause of the lack in the development of adequate means for underwater defence for warships, aside from the extreme difficulty of the problem, is to be found in the lack of information and hence in the inexact appraisal of the effects of underwater explosions in proximity to obstacles of an extremely complex nature such as those offered by the hull of a ship, incapable of resisting the attempts to which it may be subject and which, in tearing and deforming in proportion as the explosive impulse develops, forms voids which, so to speak, attract and direct the major violence of the explosion toward the interior of the hull. Too many elements have a sensible influence on the effect of an underwater explosion, as for example the distance of the hull from the center of the blow, the rapidity with which the rupture is produced in the external shell and the size of the rupture itself, the presence of free air, compressed air, liquids or solid materials in the interior of the compartment first broken into, more or less formation of splinters as a result of the external rupture, the strength of the internal structures of the ship, etc., to permit of accurate invesigation without involving practical experiments; and these in order to be exhaustive must assume such magnitude and involve such expense that only the richest nations and those most advanced in the development of their navies have thus far been able to carry out any such investigations.

Notwithstanding all these indicated deficiencies, there has been in certain navies an effort to give, in recent years, a practical direction to the search for more effective means for the protection of the hull from underwater attack, and it must be anticipated that some measure of success will reward the efforts of the most zealous. At the present time, however, there is no certain information regarding practical measures actually adopted, other than the following:

(a) Use of the well known chain net as formerly used against torpedo attack, in more or less modified form,

but which obviously can only render effective service when the ship is at rest or moving with the very lowest speed.

(b) A certain development of means for countermining, either applied to the ship itself or independent and operated from special boats.

(c) The disposition of one or more longitudinal internal bulkheads at a certain distance from the outer skin, more or less reinforced or rendered elastic by means of special arrangements, and intended to present an obstacle to the destructive effect of the explosion.

(d) The filling of the wing compartments with coal or other like solid material and intended to limit the quantity of water which can enter as a result of the rupture of the outer skin and to absorb and dissipate a part of the energy of the mass of gas and liquid and likewise of splinters driven violently by the force of the explosion toward the interior of the ship.

(e) The disposition (not followed in all cases) of a third internal skin in the wake of the most important points in the hold or in some cases of a watertight flat situated at a certain height above the central double bottom.

(f) The multiplication of watertight, transverse, very strong bulkheads in order to reduce to a minimum the number and size of the compartments susceptible of being flooded in consequence of the explosion of a mine or a torpedo.

(g) The provision of special structures in order to provide for the free escape of the engendered gases which may make their way toward the interior of the ship in consequence of the explosion.

(h) The free communication between wing compartments.

Regarding the use of special elastic means or of other measures proposed but so far as known not actually developed, no mention is made, such not yet having entered into the domain of practical application.

All the experiments carried out thus far with whatever kind of structure, tend to indicate the quasi impossibility of shielding against the destructive effect of the powerful weight of explosive carried by modern torpedoes and mines, and the almost certain deformation, more or less extended, whatever may be the structure of the ship, within a radius of 5 or 6 meters (16.4 to 19.7 feet) about the point of explosion. Two different paths are thus indicated for the further investigation of the grave problem of underwater defence: either to provide a strength of external hull sufficient to oppose an unsurmountable obstacle to the pressure of the explosion, thus reflecting it toward the surrounding mass of liquid, or otherwise to allow the results of the explosion to propagate themselves (as reduced as possible by means of well-suited external shields) to the interior of the ship, there providing suitable means for effectively controlling the destructive power and for minimizing the damage to the fighting efficiency of the ship in case of such an eventuality.

V. SPEED.

The speed of battleships of the line, since the general adoption of turbine prime movers and water tube boilers, has ranged around 21 or 22 knots until in more recent times, in which, as a result of the initiative of certain important navies, the effort has been made to develop a new type of warship, capable of uniting all the leading characteristics of ships of the line and of cruisers. It is indeed a fact that both of these types of ships have followed, in the development of the last decade, lines of progress sensibly convergent and as a result reached conditions differing but slightly in offensive and defensive quality, but in more marked degree in speed. It thus appeared logical that the two types might be united in order to realize more closely the ideal of the ship of maximum fighting efficiency.

The more important armored cruisers of the period anterior to the "Dreadnought" had from 10,000 to 14,000 tons displacement, were armed with guns of a caliber not exceeding about 250 mm. (10 inches) and were given a speed not exceeding 23 knots, while the contemporaneous ships of the line had a dis-

placement of 15,000 to 16,000 tons, guns of about 300 mm. caliber (12 inches) and a speed inferior to 20 knots.

Successively ships of the one type and the other appeared with displacements only slightly dissimilar and approximating about 18,000 tons with a heavy gun armament of the same caliber [about 300 mm. (12 inches)] but differing in the number of pieces (8 for the cruisers and 10 for the battleships) with armor somewhat lighter [about 180 mm. (7 inches)] in the former and somewhat heavier [about 250 mm. (10 inches)] in the latter. Successively also in a few brief years, the similarity between these two types of warship developed ever in more marked degree, and the cruiser type finally began to exceed in displacement the ships of the line, with the chief purpose of a notable differentiation from the latter in the matter of speed.

This evolution will appear in the most startling manner to any who will take the trouble to compare, among themselves, the English battle cruisers which followed the ''Invincible'', launched in 1907, to the ''Tiger'', in 1913. From this simple parallel it is readily seen how, in the brief period of 6 years the displacement rose from 18,000 to 28,000 tons, the caliber of the principal guns (the number remaining fixed at 8) passed from 305 mm. (12 inches) to 343 mm. (13.5 inches), the thickness of the armor from 180 mm. (7 inches) to 270 mm. (10.6 inches) and the speed from 25 to about 30 knots.

From what has preceded, it is easy to understand how, from a ship with the characteristics of the ''Tiger'' to the most recent type of high speed battleship, reuniting in itself the principal requirements of a ship of the line and of a cruiser, the transition would be easy and would involve no more than adding somewhat to the caliber of the gun armament and the thickness of the armor at the cost of a few knots of speed. The realization of this concept was reached in the recent English ''Queen Elizabeth'' and German ''Ersatz Worth'' with about 28,000 tons displacement, 380 mm. (15 inches) caliber for the 8 guns of the main battery, 300 mm. (12 inches) and upwards maximum thickness of armor and in a designed speed of about 28 knots.

Perhaps the armor of these ships does not reach the thick-

ness which, according to some, is necessary in order to enable them without other reckoning to enter the first line of battle; perhaps these ships represent a tendency rather than a definite and accomplished fact toward the ultimate fusion of the ship of the line with the armored cruiser; perhaps this same fusion, even if it be supposed to exist in the concept of the designers of the ships mentioned, should be considered as a tentative experiment rather than as a definitely established proposition. But it is undeniable that such ships as the "Queen Elizabeth" and the "Ersatz Worth" lack but little of possessing all the fundamental characteristics of true and proper battleships with high speed and with those strategic qualities necessary to enable them to serve as cruisers and with the necessary tactical characteristics to enable them to sustain the shock of the most powerful adversary, and that it would only require perhaps a further increment in their displacement and in the thickness of their armor to make of them fighting units of the highest efficiency which has yet been realized.

VI. PROBABLE LINES OF FUTURE DEVELOPMENT.

In recent times the ultimate improvements and developments in radio telegraphy and in aerial navigation seem likely in the end to exercise an influence tending toward the reduction of the types of fighting units which were first deemed necessary, and particularly toward the combination of the scout type with the torpedo type, exactly in the same manner as the progress of naval technique and the art of naval warfare have already indicated the fusion of the ship of the line and cruiser types. In any event it may be presumed that in a future, perhaps not far removed, the active fighting naval units, excluding all material destined for auxiliary service, may be reduced essentially to two types of ship as follows:

(1) Ships of the line, with powerful gun armament, and adequately protected against every kind of attack.

(2) Torpedo scout boats (floating and submarines) armed primarily with torpedoes, agile, with high speed and difficult to be seen.

Continuing in the present paper to consider the battleship type only, it is well in this connection to turn the attention

toward the future in order to fix the principal lines of probable evolution of this type. But how can this be done at the present moment, in which is in progress, one may say, the most terrible test of battle which has ever been known for the naval equipment of the greatest maritime nations in the world. Such a task appears beyond measure difficult, especially in view of the imperfect knowledge which we have at the present moment regarding the particulars of the recent naval actions. From a general examination, nevertheless, of the results which the science and art of war have indicated thus far, it seems to be possible to draw some indication of the directions, which perchance will not greatly differ from those which will be actually followed in the near future by the lines of evolution of this type of ship.

To this end, a point of departure may be taken with a displacement predetermined and varying about 32,000 tons; a displacement which, in the present state of naval technique gives sufficient opportunity, if properly utilized, to permit of developing a ship of war more powerful than any now existing among those at present in service, in construction or under design, at least so far as their principal characteristics have been made known.

As is well known to all students of the arguments considered in the present paper, much has been already written and still more discussed, regarding the number, the caliber and the position of the guns best suited to a modern battleship, regarding the speed which such a ship should be able to reach and regarding the protection best adapted to adequate defence from every kind of attack. The variation in the opinions expressed in regard to these matters is, however, so marked and the opinions even in open opposition are moreover so authoritative, that it must be accepted as beyond measure difficult, if not altogether impossible, to bring them into such harmony as will permit of drawing practical conclusions. The great fighting unit, as it is outlined today in the desires of all naval powers, should be superlative in everything; that is to say, as well in means of defence as in those of offence, as well in radius of action as in speed. The most sensible plan to suggest to the designer seems to be that of devising a ship which shall repre-

sent, in the fighting sense, an incontestable improvement over similar contemporaneous units in regard to the fighting characteristics, or at least in the major part of them, giving to the results of practical experience greater weight than to simple opinions, no matter how competent they may be.

In order that the fighting characteristics may be adjusted in such manner as to render the ship under design, with equality of displacement, superior in a fighting sense to any other now in existence, it is necessary to accept the following six fundamental principles:

(1) Suppression of everything not absolutely required for purposes of naval warfare or for life on shipboard.
(2) Reduction and simplification to the maximum degree of all auxiliary services.
(3) Reduction to the minimum area of the target offered by the above-water body.
(4) Adequate protection of the vital parts in the largest sense of the word.
(5) Definite separation between the compartments necessarily hot and those to be maintained at a low temperature.
(6) Maximum arc of gun fire.

The rigorous application of such principles, joined to an equable division of the displacement between the demands of the offensive and the defensive characteristics, between those of speed and of radius of action, will give without doubt to the ship in question the maximum possible efficiency, which is the same as saying, the maximum return on the investment involved and the maximum fighting advantage for the country to which it belongs.

It is often said that a warship represents a compromise; further that it must in effect satisfy manifold and varying demands, some of which are in mutual opposition among themselves. Having in view, however, the exceptional economic and military importance of the great modern fighting units, it becomes of special importance to guard lest the compromise may involve damage to the best coordination of the essential fighting qualities, which constitute the true and only reason for the existence of a ship of war.

The growing interest of public opinion in naval problems, the treasures of experience accumulated by the studious and by the practical, the lessons drawn from the most recent naval battles, the awakening and rapid development of the naval sentiment in all classes everywhere, all these have dealt summary justice to these hybrid concepts, due to the influence of political and military views excessively narrow and one sided in scope, or to a febrile search after the unusual. With rare exceptions there are no longer admitted to any great navy, ships in which the effective function is tied to particular conditions of the adversary or theater of action, or ships of striking appearance better adapted to strike powerfully the imagination of the onlooker than the strongly armed sides of the enemy's ship.

Not only by reason of the serious difficulties of various natures which a modern ship of the line involves, but also by reason of the heavy financial burden which is imposed, and further by reason of the obscure presentment, from which no nation can escape, of the incalculable and irreparable disaster to a country vanquished on the sea, it is absolutely necessary that between him who designs and him who is called to take the ship into the line of battle, there should be extended the hand of mutual cooperation in order to assure, on the part of both, the practical application of the six fundamental principles noted above, even at the cost of notable though reasonable sacrifices demanded of the personnel of the ship.

Such an understanding should form one of the cardinal principles of the professional education of the modern naval officer, as well as the point of departure of a new orientation in the art of naval construction directed resolutely toward the most efficient, rapid and economical preparation of war material, destined to the supreme purpose of battle at sea.

The six fundamental principles above noted are not irreconcilable among themselves and even aid mutually in application, as is obviously evident when it is noted how the suppression of whatever is not indispensable to combat and to life on shipboard permits the limitation of the superstructures and of the upper decks (which is equivalent to the reduction of the target offered to the enemy's guns), leaves the extra margin of

weight disposable for more adequate protection of the vital parts and permits at the same time the largest possible arc of fire for the offensive armament. On the other hand the inevitable reduction in the living spaces imposes a corresponding reduction in the number of the crew and such reduction is rendered possible by the utmost simplification in the various auxiliary services, while the definite separation in the grouping of the hot compartments and those to be maintained at low temperature facilitates in its turn the simplification itself.

VII. PRACTICAL EXAMPLE.

A ship of the line of about 32 thousand tons displacement responding, according to the most modern views and the most recent advances in naval technology, to the requirements of the maximum fighting efficiency, will be here described with the characteristics which have been above briefly set forth.

(a) Structure and Arrangements, Internal and External.

The hull of the ship under discussion is supposed to be constructed on the Isherwood type of longitudinal framing and with such scantlings as to insure exceptional stiffness and strength. The transverse watertight bulkheads reinforced in manner to constitute a solid support for the longitudinal members are spaced at intervals of from 3 to 7 meters (10 to 23 feet). The outer skin of the hull has separate layers of special steel throughout the zone of the double bottom from the lower margin of the armor plating nearly to the keel. The sides of the ship are divergent above water, even in the central part of the ship. The structure of the double bottom is absolutely independent of that of the outer skin. The double bottom is very high and roomy with the inner skin of extra strength and of similar structure in certain zones like the outer skin. It may be divided into three distinct parts; a central part (in the zone not in danger from underwater explosions) kept normally empty and dry; an intermediate part (wherein some danger from underwater explosion may exist) constantly kept filled with water or liquid fuel; and a lateral part (wherein is found the greatest danger from underwater explosion) kept always filled with coal in the wake of the motive power equipment, and with any suitable material for the remainder.

The structure of the ship comprises six longitudinal bulkheads of extra strength, disposed in pairs, with an intervening space of about 1 meter between each pair. The interior is thus divided by the three pairs of bulkheads into four zones, of which the two innermost constitute the part of the ship securely protected against the disastrous effects of underwater attack, and here may be placed those organs of the ship which must be most carefully preserved against the attack of the enemy. The usual form of protective deck brought down below the water line outboard, is suppressed and in its place are provided two reinforced decks, the upper one continuous from stem to stern and the lower one interrupted in the wake of the propulsive equipment.

In all the central zone, comprising the space covered by the emplacements of the heavy and intermediate guns, that is to say for a space of about 92 meters (300 feet) of length, the ship is of limited height above the water, so that the freeboard is only some 2.75 meters (9 feet) above normal load line. Such is the indispensable condition for combining the triple objective of the minimum target, of a broadside effectively protected and of armor plates suitably inclined with respect to the most probable trajectory in order to offer the maximum resistance to penetration.

In order to assure good nautical qualities to the ship and a suitable height above the water for the heavy guns, superstructures are provided forward and aft with heights respectively of 7 and 6 meters (23 and 19.6 feet) above load line. Every other superstructure is suppressed, with the exception of the single smoke stack, the military mast, armored conning towers and fire control stations, tops for search lights and the emplacements necessary for small boats.

(b) Guns and Munitions.

The principal armament comprises 10 guns of 381 mm. (15 inches) caliber, 45 calibers in length, subdivided into two groups of five each, at the bow and stern of the ship. The five guns of each group are disposed in one turret with two planes of fire, three guns in the lower plane and two in the upper plane, in a similar manner (save for the number and caliber of the guns) as in the American type "Nebraska"; that is to say in

such manner as to give at each end of the ship a single emplacement with arc of fire throughout 320°. The height above the sea of these guns is as follows:

Emplacement at bow, 12.5 meters (41 feet) for the upper line of fire and 10 meters (32.8 feet) for the lower.

Emplacement at stern, 11 meters (36 feet) for the upper line of fire and 8.5 meters (28 feet) for the lower.

Each gun is provided for 100 shots.

The secondary armament comprises:

(1) Twelve guns of 190 mm. caliber (7.5 inches), 50 calibers in length, subdivided into four emplacements of three guns each, located two toward the bow and two toward the stern with line of fire lying outboard of the heavy gun positions, and each with an arc of fire of about 180° from the line of the keel. The height above the water is as follows:

Emplacements forward, 7 meters (23 feet).

Emplacements aft, 5.5 meters (18 feet).

Each gun is provided for 130 shots.

(2) Twenty eight guns of 102 mm. caliber (4 inch), 50 calibers in length, of which 18, of the disappearing type for high angle fire up to the vertical, are distributed along the uncovered central deck between the two superstructures, 9 on each side; 6 are installed in battery at the bow as bow chase guns and 4 in battery at the stern as stern chase guns. The height of the line of fire above the water varies between 4 and 5 meters (13.1 and 16.4 feet).

The torpedo armament consists of 8 lateral underwater tubes for torpedoes of 533 mm. diameter (21 inches) arranged in two separate chambers, one toward the bow and one toward the stern between the motive power equipment and the ammunition and store rooms.

The battery of search lights comprises 10 twin installations, of which 5 are carried on the military mast, four on the smoke stack and one is carried at the stern on a special platform which may be dismounted when the ship is cleared for action.

The ammunition rooms are grouped in accordance with the guns, toward the two extremities at bow and stern outside the spaces for propulsive equipment and of the network of steam

pipes, in order the more readily to insulate them from the principal sources of heat on board and thus to hold them at a suitable temperature, even in the absence for a time of the aid of the refrigerating plant, on the continuity of the service of which it is not prudent to count too far, especially during the development of a naval action.

To a considerable extent the munition and storerooms both at the stern and at the bow are arranged between the doubled lateral bulkheads right and left, intended, as will be seen later, to form a barrier impassable to the results of underwater explosions, wherein they may be reasonably considered as safe from any war hazard, and in this location especially well protected, it is assumed that by preference all war munitions will be stored and in particular all explosives.

The outer compartments all along the length of these storage spaces, both at the bow and at the stern, are supposed to be kept constantly filled with light displacing material, intended to limit the invasion of water in case of rupture of the outer skin and to absorb and dissipate a part of the energy produced by underwater explosion.

Capacious and suitable passage ways are assured between the two groups of ammunition rooms at bow and stern by means of the spaces between the three pairs of bulkheads which extend through the propulsive machinery compartments, and which are also intended to contain the electric circuits and the transmission and piping systems of chief importance.

Suitable passage ways are also assured between wing compartments.

(c) Protection.

The efficient protection of the ship against gunfire is assured first by the very greatly reduced area of target and further by an extended and effective distribution of armor over the exposed sides, and finally by a suitable inclination of the above sides with respect to the vertical. The first of these provisions is effected by suppressing all that part of the above water body which is not absolutely necessary for military uses, for nautical demands and for life on board. The proportional reduction of target area which may be realized without inconvenience in comparison with a ship of the line of the ordinary type may

reach 25 percent; whence we may consider a like reduction in the probability of being struck. The second of the above mentioned provisions will be the more readily realized, the more radical the development in the first and the greater the inclination which can be given to the side relative to the vertical, such inclination being inversely proportional to the thickness of the armor necessary to confer any predetermined degree of resistance to penetration. It is understood that the ship is to be suitably protected from the attack of guns of approximately 400 mm. caliber (16 inches) by means of armor plate of a maximum thickness of 300 mm. (12 inches) and a minimum of 150 mm. (6 inches), entended over the entire area along the water line above and below, over most of the above water body, over the base of the single smoke stack to a height of about 5 meters (16.4 feet) from the open deck, and over the transverse bulkheads for protection against raking fire. For the protection of the principal guns, where the local conditions prohibit the suitable inclination of the armored surface with regard to the trajectory of the most probable fire, the armor plates will possibly reach a still greater thickness. All the horizontal decks and especially those which are uncovered, are protected by the exceptional strength of their structure, longitudinal in type (as noted above), by their accentuated transverse curvature, and finally by separate layers of special steel, suited to resist the attack of heavy projectiles with the smallest angle of incidence, or from the fall of explosives from the air, contributing at the same time, wherever installed, to the necessary organic rigidity of the structure.

The protection against subaqueous attack is based upon the following fundamental concepts:

(1) To confer on the outer skin of the hull, throughout the zone rendered liable to attack either by torpedoes or mines, a special strength against rupture by means of many layers of special steel, solidly supported by the transverse watertight bulkheads, and reinforced by means of longitudinals especially strong and continuous from bulkhead to bulkhead.

(2) To substitute for the ordinary double bottom which, by reason of its rigid connection with the outer skin involves the disadvantage of following the deformations of the latter, a

strong internal skin effectively independent of the outer skin of the hull, but of equal strength and of similar structure.

(3) To double the usual distance between the two skins of the ordinary double bottom, carrying it to about 2 meters (6.5 feet) in the horizontal parts in less danger, and to about 2.5 meters (8.2 feet) in the vertical parts in greater danger.

(4) To carefully avoid, between the external and the internal skins, vacant spaces which following a possible rupture of the hull fulfill the evil office of drawing toward the interior of the ship the chief violence of the explosion. It is understood that the intervening space between the two skins (external and internal) is, throughout the zone in greatest danger, to be kept always filled with coal or other like material, capable of absorbing and of dissipating a part of the energy of the explosion and of stopping the splinters coming from the supposed piercing of the skin. In the zones in less danger the similar spaces may be utilized for fuel oil.

(5) To dispose on each side, at about 5 meters (16.4 feet) from the inner skin and at about 7.5 meters (24.6 feet) from the outer skin, two strong longitudinal bulkheads, independent one from the other and separated by a distance of about 1 meter (3.28 feet) from each other and destined to stop absolutely all residual effects of any explosion which might by chance have overcome the preceding obstacles, and thus to safeguard in full security the interior of the ship, destined to contain the most important and vital organs.

(6) To provide a minute subdivision into compartments by means of strong and closely spaced watertight transverse bulkheads in case of rupture and inflow of water.

(7) To provide by suitable means for the ready escape upward, of the products of any explosion which might by chance penetrate into the interior of the ship.

(8) To provide ample and free communication between wing compartments for balancing purpose.

The efficient defense finally against aerial attack, in the present condition of things, is sufficiently assured through the protection, as previously noted, of the open decks and their form markedly curved in the transverse direction, as well as by suitable screens or hoods arranged over the smokestack, venti-

lators, fighting tops, search lights, port openings and in general over all apertures in the open decks.

(d) Propulsive Machinery, Speed and Radius of Action.

The boilers, light weight in type with subvertical water tubes, are all grouped forward of the machinery space in such manner as to facilitate the escape of the products of combustion through a single smoke stack. Ten of the boilers are arranged for burning either coal or fuel oil and ten for the use of fuel oil alone. Each boiler is placed in a separate compartment and ten of them are located in the interior of the ship with respect to the double bulkheads, giving absolute protection against the effects of underwater explosions so that full assurance may be realized in any emergency.

The prime movers (turbines) are four in number, completely independent among themselves, and each driving a screw propeller. It is not consistent with our present purpose, having in view the nature of this paper, to enter into any detailed discussion regarding the convenience of having the turbines connected directly to the shafts of the propellers rather than on separate shafts and connected to the propeller shafts by gearing or hydraulic or other form of reduction; of having special turbines or prime movers of different type for cruising, etc. It may, however, be noted that two of the main turbines are located in that part of the ship destined to safeguard, against every danger, the most important and vital organs, in such manner as to constitute, with the ten boilers situated in similar conditions of safety and with the corresponding piping, a propulsive equipment of about two thirds the normal full power which may be called the "safety propulsive equipment" and on which it will be reasonable to count during the course of any naval action and so long as the ship remains in a condition rendering navigation possible.

The maximum speed of the ship in action, that is to say the speed practically obtainable under whatever conditions or at any instant whatsoever with the fullest assurance, but with the entire propulsive power, is taken at about 26 knots which will imply under normal conditions the possibility of reaching a speed of 27 or 28 knots. The radius of action may be examined from two points of view according as consideration is directed

toward the maximum capacity disposable in the fuel compartments, solid or liquid as it may be, or otherwise the maximum weight of combustible intended for the normal draft of the ship. The radius of action related to capacity is evidently greater than that related to weight, thus permitting the ship, in exceptional circumstances, to take on an excess of combustible without seriously encumbering the spaces destined for other services.

In the ship under consideration space has been provided for a coal capacity of about 1500 tons, and for a liquid fuel capacity of 1000 tons, which it is deemed will assure a sufficient radius of action for the ship.

In fighting trim the wing coal bunkers should all be kept constantly filled, below the armor belt. The purpose of this coal is essentially defensive and it is expected to minimize the effects of underwater explosions.

Independently of the weight and of the nature of the combustible on board, the radius of action will be so much the greater the less the consumption of the combustible itself per mile at the most economical speed, whence the cruising speeds will be most effectively adjusted by means of experimental investigation in order to minimize the consumption of the prime movers.

It should be further noted that a large radius of action joined to a rapid re-fueling, are equivalent by their practical effect not alone to a notable increase in speed, but they secure also a sensible reduction in the inevitable risks which are incurred whenever a naval force is compelled to seek refuge as a necessity for re-fueling.

Whenever therefore the strategic objective is found in the waters of the enemy and all ships aggregated in the operating force must become subject to the need of fuel and stores, the question of the radius of action will rise to such importance as to exercise a preponderant influence on the possibility of a successful outcome to the enterprise.

The design under present consideration is represented in outline by three illustrations as shown herewith.

There is also included a plate containing the profiles of the more recent warships of the principal navies and that of the ship here outlined.

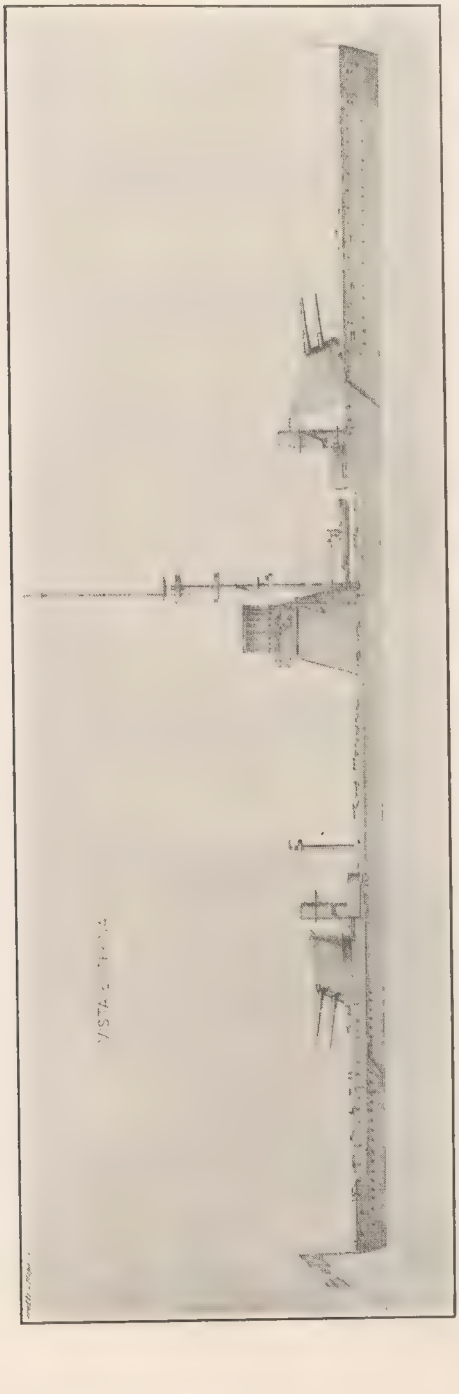

Fig. 1. General View.

Fig. 2. Plan of Open Deck.

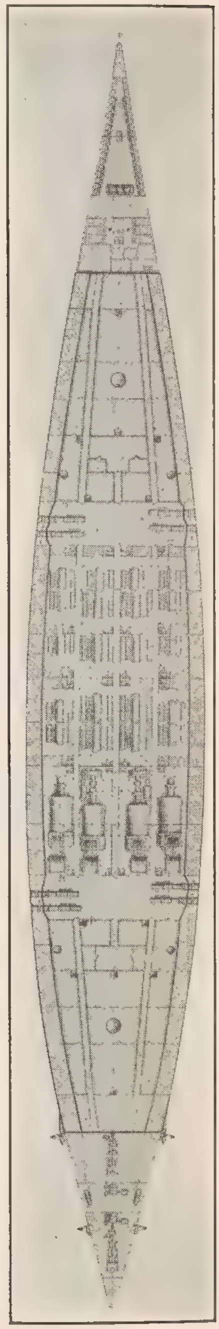

Fig. 3. Plan of Machinery and Munition Spaces.

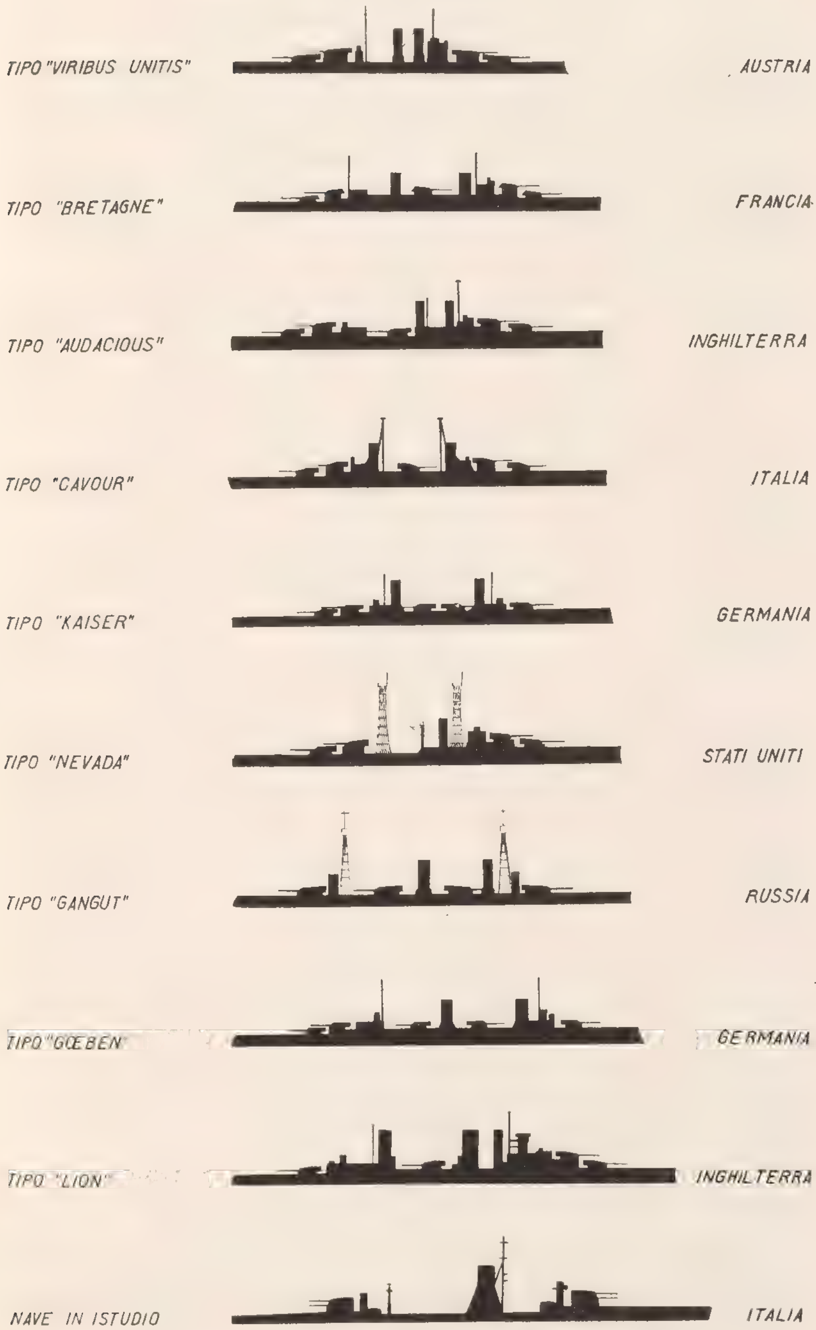

Fig. 4. Profiles of Recent Battleships of the Principal Navies.

DISCUSSION

Admiral Kondo.

Admiral M. Kondo,‡ asked what relative importance is attached to armor protection of armament and hull.

Admiral Capps.

Admiral W. L. Capps,† said that Admiral Kondo's inquiry was really addressed to the Author and that the Chair did not feel competent to answer; that it was a very fundamental question, however. He stated it is easy to realize that no matter how well protected a ship's armament might be, if the hull should be injured to such an extent as to give the ship a heavy list, the effectiveness of the armament might be entirely destroyed. In other words, it is as necessary to protect the gun platform, the hull of the ship, as the guns themselves; that is, the aim should be to do as much as possible for the protection of both. Like all such questions, this one is usually settled by compromise.

In this connection he wished to acknowledge our debt to Italy for first putting forward the idea of the big ship and also the now recognized principle that you must employ the largest gun possible with a given size of ship.

Admiral Kondo.

Admiral M. Kondo wrote that he thought, when the wing spaces of a ship are filled with solid materials, there is always some danger that they (solid materials) themselves may act as splinters and add to the damage of the interior.

Referring to Part VII, he stated that according to the sketch plan and according to the description, five heavy guns appear to be mounted in a single barbette, three on the lower plane and two on the upper. He asked if there is not some difficulty in supplying munitions for guns of such size? In the American ships the two upper guns are very much smaller—the shells would be only about ⅛ the weight of those for the heavier guns.

The reasons for mounting medium calibre guns were not apparent and, as far as he could ascertain, were not stated in the paper. He should, therefore, be glad to know them if possible.

He also noticed that the depth of the ship is small amidships, just where the bending stress is greatest. As far as his limited experience went, he found that even with a comparatively great depth, the scantlings of the upper members attain a very considerable magnitude and he would like to know if any special means are provided to secure the requisite strength. It might be that the conditions are different in the Mediterranean from those obtaining on the Pacific, but he would be glad of further information on this point.

Col. Ferretti.

Col. E. Ferretti, in his closing remarks, states that he entirely subscribes to Admiral Capps' reply to Admiral Kondo's remarks about relative importance attached to armor protection of armament and hull. As to the other remarks of Admiral Kondo's, about the difficulty in supplying munitions for the five heavy guns of each barbette, about the reasons

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Col. Ferretti.

for mounting medium-calibre guns and about the reduced depth of the hull amidships, he begs to answer that: first, he thinks no serious difficulty is to be expected in supplying munitions for the five heavy guns in each barbette; second, the 10-inch guns are intended to substitute the 6-inch guns which have formed, until the present, the secondary armament of modern battleships; third, no special means, other than convenient proportions given to the upper members, are provided to secure the requisite strength of the hull, in spite of the reduced depth amidship.

Paper No. 205

THE SUBMARINE.

By

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At the time that I accepted the invitation of the Committee on Papers of this Congress to prepare a paper on Submarine Boats, the present war had not been thought of, except, possibly, in the minds of those in higher authority abroad.

The submarine boat to the majority of the population of this country certainly, and probably of all nations, was a more or less theoretical weapon of untried power. Today, there is probably no military weapon which inspires greater interest in the minds of the average citizen, and as it embodies applications of many different forms of engineering, it is a subject of profound interest to engineers. I, therefore, esteem it an honor to have been permitted to prepare a paper, but have found it somewhat embarrassing to know just where to begin and where to leave off.

A great many excellent papers and books have been written by engineers interested in the design and production of submarines; and the operations of the submarine, during the present war, have inspired probably as many paragraphs in the press as have been written on any one subject. A great many of these newspaper paragraphs, written as they are by people not versed in the submarine, have contained errors which are obvious to engineers, but on the whole, the information given in this wise has been correct, and it has certainly brought to the attention of the several nations the necessity of having an adequate number of submarines for national defense.

Government	British	British	British	British	British	British	German	German	German	German	French	French	French	French	French	French	French	French	Japan	Austria	Russia	Italian	Italian
Name	E 1 to 18	F-Class	G-1	V-Class	W Class	S Class	U 13 to 24	F.I.A.T	U-25 to 30		Diane-Daphne	Imp Zédé Type	Bellone Class	Clorinde Cl.	Gustave Zédé Néréide	Admir Bourgois	Mariotte	Archimede	16-17	U 12 to 14	Kashalot	Cavallini Laurenti Type	F I A T
Number Built	18	8	1	4	4	4	12	1	6		2	7	3	8	N, 2	1	1	1	2 New Schneider	3	6	8	2
Length Over all	176' 0"					234'	213' 8"	210'	214'-1¾"		223	246		177	239.5'	184'	213'	212'			212'	210'	210'
Beam and Depth, where obtainable)	23' 0"					22'	20'	19'6"	20'		18.5 x 12.5	21 x 13		16⅜ x 10¾'	19¾ x 15'	26¼ x 12'	14' x 12½'	22⅓ x 20'					19'6"
Displacement Surface Tons	725	940					650	676	750		630	830	520	410	740	555	530	577	520		650		676
Displacement Submerged "	810	1200	1500	1050			750	830	900			1070	610	550	1000	735	630			1000	950		830
Reserve Buoyancy %									56%														
				Vickers Special	Elswick-Laubeuf	Scott F.I.A.T. -Laurenti.																	
Maximum Speed - Surface Knots	16	20	24	19		20	14	18	20		18.5	19	17.5	15	18	15	15	15	17.5	18	17	18	18
" " Submerged "	10	12	18				8	10	10		9.5	11		9.5	12	10	10	10	9	10	11		10.
Cruising " Surface "								10						10	10			10					10
" " Submerged "								5										5					5
Surface Radius - Cruising Speed, Naut. Miles.			2800					3500						1500	2300	2000		2000			5000		3500
Submerged Radius - Max. Speed Hours								1															1
" " Cruising Speed Miles			900					90										100					90
			Exposed portion of hull armored to withstand 6" shell at max. torpedo range							Unauthenticated reports of a giant sea-going submarine with a cruising radius of 40 days					or 1700 M @ 14 K			Fitted with 3 horizontal and 1 vertical rudder					
Engines - Number	2							2														2	
" Type	Diesel	Heavy oil	Steam Turbine					Heavy-oil F.I.A.T.	Oil		Diesel	Steam	Diesel	Diesel		Diesel	Petrol	Steam				F I A T	Heavy-oil F.I.A.T
" No of cylinders per engine								6														1500	350
" Brake Horsepower Total	1750	5000	6500				1400	1300	4000		1800	4400	2100	1300	4800	1560	1440	1700	2100			6	6
" Corresponding rev per minute																						350	345
Motors Type and number	?																						
" Total rated b.h.p. 1 Hour	600	2000	2400				500	1020															
" " " " 3 Hours																							
Batteries - Type of Cell																							
Number of Cells																							
Ampere-hours capacity																							
Armament - Torpedo Tubes	4	6	4 Bow-4 Stern				2 Bow-2 St'n.	2 Bow 2 St'n			10	8	8	8	8	7	6	7	6	5	8	2 Bow-2 St'n	2 Bow-2 St'n
" Torpedoes Number		10						6														6	6
" " Type	21"						Disappearing	6900×500 mm			←			18" Whitehead 1904				→				6900x500 mm	6900x500 mm
" Guns Number	?		2			2	1 14 Pdr					4										2	
" " Type	12 Pdr Q.F.	2-3" Q.F.	4" Q.F.			4" Q.F.	2-1 Pdr for					9 Pdr.											
Complement	28	About 25					high angle fire				35	40	29	27	40	25	28	26					
References.																							
Naval Annuals and miscellaneous published articles																							
																						3-27-15	Robinson

Note:- Uncertain whether the 6 boats are all of the dimensions given

Historically, the submarine is not at all a new idea. Practically, as a useful weapon, its age is young.

I fear that if I attempted to write any historical matter with regard to the submarine, I could only go over, again, ground that has already been well and amply covered. If I attempt any engineering discussion of the principles embodied in the smaller types of submarines, it would be unfair to the members of this Congress, who are doubtless thoroughly familiar with all the principles contained in the submarine and their application to the boat itself. Therefore, it seemed wise to confine this paper to the limitations of the present day submarine, to the engineering problems to be expected in the development of the sea-going fleet type of submarine, and to glance at the visible and prospective methods of solving the problems of development desired.

Up to 1912 or 1913, the submarine was a vessel of 130 to 165 feet as a limit of length, with a surface speed of 12 to 14 knots, and with a submerged speed of 9½ to 11 knots. On the surface, the radius varied from 1500 to 4500 miles, and submerged, a radius of about 3 hours at 8½ knots was obtained, with a longer radius at slower speeds. It is largely from vessels of this general type that we have heard during the present war.

Offensively, these are vessels that can best operate against the enemy singly, mostly in the form of raids and by attacking blockading ships or ships whose general habitat is fixed, due to their duties, or by attacking merchant ships or their convoys following the recognized trade routes. Defensively, this type of submarine fills a much needed want and may operate singly or in groups from a fixed or movable base in such a way as to hinder blockade or make invasion almost impossible.

By this time, i.e., 1912 or 1913, the submarine had so far proven to the military student its power and its menace that there arose a demand for a type that could accompany and supplement the battle fleet in its operations and action on the high seas. To enable a submarine to do this, two qualities are essential. First, seaworthiness, which means not only staunchness, but the possibility of a crew inhabiting the boat without excessive physical or mental strain during long and distant journeys; and second, increased surface speed, to permit the

submarine to keep up with the parent fleet in its operations and maneuvers up to and on the scene of battle.

There has always, and naturally, been a demand for increased submerged radius and speed and for increased armament, though these features were only natural directions for increase and not qualities necessarily essential in the case of the smaller coast and harbor defense types.

We therefore see the fleet submarine projected to include the four increased characteristics over the coast defense type, of greater seaworthiness, greater surface speed, greater submerged speed and radius, and increased armament.

The submarine, in comparison with its surface sister, the "destroyer", has always the disadvantages of requiring two sources of power, one for surface and one for submerged work, and of requiring a heavy hull for withstanding the pressures of water to which it must be subjected in submerged work.

A brief consideration of this fact will indicate how expensive a proposition the four increases referred to, become.

HULL.

The types of submarines that have been usual up to the present, at least in the United States, German and British services, have had a single hull with all or most of the ballast tanks inside. The French and Italian types, even in the smaller sizes, started with the double hull, but in the smaller sizes at least, have thereby suffered a penalty in the matter of performance, due to the greater proportion of weight assigned to the hull.

In the single hull type, the cross section of the hull is usually circular, with elliptical sections at bow and stern. The elliptical sections usually have major axes vertical at the bow and horizontal at the stern. Such a form gives an excellent shape for submerged work, is economical of weight and is sufficiently good for the moderate speeds on the surface required in this type.

The large seagoing type, requiring as it does a surface speed of at least 20 knots, necessitates another form, more nearly approaching the surface ship in shape.

This ship shape and the requirements of pressure test, etc., that the boat must fulfill, naturally lead to the use of the double

hull type, the external hull or lighter hull being nearly of the conventional ship-shape form, with the inner, or pressure hull, of the usual circular cross section, the space between the two being utilized as water ballast space. For the long distance cruising that the type must do, a greater proportion of the hull must be above water in the surface cruising condition than in the case of the smaller or coast defense type, i.e., there must be a greater percentage of reserve buoyancy, not unusually running up to 40%.

Some types of the smaller size have watertight superstructures and others non-watertight superstructures. Practically all seagoing submarine projects have the watertight superstructure in some form. In some projects for seagoing submarines, it has been proposed to have a watertight superstructure to provide space for use as living quarters for the crew in surface work, in the same way as the 'tween deck space on a torpedo boat or "destroyer". I believe, that a boat of this type will be the ultimate answer for really seagoing work, giving as it does many of the virtues of the regular surface ship in combination with the qualities of the submarine.

To provide for the safety of the vessel when damaged and to properly segregate the multifarious activities that obtain on a vessel of the seagoing type and size, close and ample compartmenting must be employed. To make such compartments actually useful in a submarine and to withstand the pressures to which they may be subjected is no easy matter, as the scantling of bulkheads and stiffeners must be massive and the fastenings strong.

The increase in surface speed required in the fleet type of submarine, leads to a large increase in length. Lengths from 275 feet to 300 feet are very probable for such boats in the immediate future.

Stability and other considerations demand a considerable increase in diameter or beam. The increase in diameter leads to increased scantlings to withstand a given pressure of submergence, which considerably accentuates the difficulties of the development.

With the greatly increased length necessary in the type, questions of control in the vertical plane enter into the problem,

and it may be reasonably assumed that multiple horizontal controllable planes, always a desirable feature as tending to greater safety and delicacy of submerged control, will be found necessary in this type of craft.

ARMAMENT.

The armament of the submarine varies with the type and size. The conventional arrangement on the coast defense type is a group of fixed torpedo tubes in the bow and a single tube or group of tubes in the stern, loaded from the interior of the boat. Not more than two torpedoes for each tube are known to be carried on any type in existence.

The internal tube, loaded and fired from within the boat, is, all things considered, the most satisfactory, but it is restricted as to numbers, even if both bow and stern tubes are used, due to the location that the tubes must occupy and the size of the craft.

There are certain submarine operators who do not believe in the use of stern tubes, on account of the disturbance to the torpedo's action that results from the propeller race, the following wake, etc.

With the growth of the size of submarines, it becomes increasingly important to provide a place for more torpedo tubes, so that the increase in torpedo armament may keep pace with the increase in size of boat.

There are several possible solutions of the problem:

(a) External longitudinal fixed tubes paralleling the internal longitudinal fixed tubes.
(b) External launching tubes of the Laubeuf type.
(c) External launching frames of the Drzewiecki type.
(d) External rotatable tubes.
(e) Internal broadside fixed tubes.

(a), (b), and (c) present difficulties as to gyro adjustment, more or less insurmountable, and with the steel-bodied torpedoes used in some navies present the difficulty of permitting rusting of the body.

(b) and (c) have the objectionable feature of introducing errors into the torpedo's motion, due to the manner of launching.

(d) has certain difficulties as to firing at an angle with the keel when the submarine is underway, due to the stream lines, passing the tube, tending to jam the torpedo as it leaves the tube, or in affecting the angle of discharge.

(e) is a type limited in application to a boat of large beam, but with the advent of the seagoing type of submarine it would seem to present a wholly reasonable and desirable solution of the question.

The usual submarine torpedo is 5.2 meters (17.06 ft.) long and 18 in. diam., having certain special features to fit it for submarine work, but otherwise not ordinarily different from the 18″ torpedo used on other ships. These torpedoes usually have an explosive charge of about 200 to 400 lbs., an effective range of 3000 to 4000 yards at about 25 to 30 knots speed.

It is said on very good authority that the German submarines fire a special torpedo having a less range and a considerably large charge. For the special work of sinking merchantmen, which the German submarines have been engaged in, a very small torpedo of short range, of which a large number could be carried, would seem to be desirable.

With the seagoing type of submarine, there would seem to be nothing to prevent the use of the 21-in. torpedo of the type used on battleships, which have been developed to a range of 12,500 yards at 27 knots.

In view of the probable use of this type of submarine in a fleet action against a fleet or squadron in formation, where the chance of hitting at long range is good, by "firing into the brown" at the formation rather than at the single ship, the long range torpedo will be more justified than is the case in the defensive or raiding tactics peculiarly suited to the present smaller sized submarine. It is the consensus of naval opinion, which seems to be borne out by the facts of actual war, that fleet actions at sea, after having been joined, will develop into one or more actions between ships in column and steering on substantially parallel courses.

Capping is, of course, aimed at, and when it can be accomplished, is most effective.

A highly desirable role of the submarine in such an action would be to be held in the lee of the line until a favorable oppor-

tunity occurs, when it should be able to rush across the gap between the fleets and launch its torpedoes at the enemy's column. To do this, requires a high submerged speed, for say 10 to 20 minutes. If a speed of 18 knots submerged could be obtained for this length of time, the submarine could be a vitally important adjunct to the battle fleet in action.

In the absence of such a speed, the submarine's role in a fleet action at sea would seem to be to submerge in a predetermined area and let the fleet commander maneuver to bring the enemy into the danger zone of this "portable mine field".

Guns.

The use of a fairly small calibre gun is becoming prevalent. These guns, at present, do not exceed 3 in. in calibre, and are usually fitted for high-angle fire for use against aeroplanes.

As, at present, the only two known methods of successful operation against submarines are ramming tactics on the part of surface vessels and bomb dropping from aeroplanes or dirigibles, it is necessary to provide means to oppose the air craft's activities.

The types of guns used on submarines are various in the different naval services of the world, but all are essentially of the housing type, so fitted as to be withdrawn into a fairwater, or into a recess, and so produce a minimum of resistance when operating submerged.

So far, not more than two such guns are known to be fitted per boat, but with further increase in size of the submarine, there seems no evident reason why the number and calibre of guns might not and should not be reasonably increased.

PROPULSION.

Surface Propulsion.

Modern submarines are usually propelled by heavy oil engines of the Diesel cycle. The attempts at the rapid developments of this type of engine, necessary to keep pace with the possibilities of submarine development, have not, however, been uniformly successful. In other words, the demand for submarine development and its possibilities is, so far, moving faster than is the case with the Diesel engine. The crux of the question of the development of the seagoing type of submarine today lies in the development of the prime mover for surface

propulsion, and too much stress cannot be put upon the necessity for development along this line.

The Diesel engine is still, in some respects, in a not fully perfected state, even for the heavier type of marine installation used in cargo carriers, etc., and the submarine engine presents problems that greatly accentuate the inherent problems of the Diesel type.

In the smaller sizes of submarines, the Diesel engine, 4 cycle or 2 cycle, reversible or non-reversible, may be said to be on the high road to satisfactory development. By this is meant engines in units up to 1,000 or 1,200 b.h.p. each.

In a seagoing submarine of the size now desired, and in most respects quite possible of attainment, the horsepower required reaches from 4,000 to 10,000 and may even reach higher. If this be the case, the number of units becomes rather large if the Diesel engine be adhered to; or some new development is necessary, such as the double acting type; or recourse must be had to some other type of surface drive to satisfy present demands and until the Diesel engine development shall have caught up with the development in submarines. This naturally leads one, for the solution of the immediate problems, to the consideration of steam propulsion.

Steam Propulsion.

The general development in marine steam installations has tended greatly toward solving the problems encountered in the earlier steam installation on submarines.

Oil, as a fuel, can now be obtained and can be used under a boiler in a satisfactory manner. The water tube and flash types of boiler have been developed to a high state of mechanical and thermal efficiency. The turbine has become a proven prime mover. These, with other developments in marine steam installations, may be said to have brought the steam propulsion of submarines to the point where the only really important obstacles remaining are the problems of the sealing of the boat for submerged work and of dissipating the heat when ready to seal up and submerge.

Several of the foreign powers have installed steam plants for surface propulsion and, it is understood, with some success. The details of these installations are not available.

The writer and his associate engineers have propositions under development whereby it is believed the drawbacks referred to above can be minimized or avoided and the steam installations made practicable; but in view of the peculiar state of the submarine industry in America, he prefers not to exploit the same at this time.

Electric Propulsion

Combined with the possibilities of steam propulsion, electric propulsion, both on the surface and submerged, presents an interesting field for investigation and thought.

Here also, the developments of the kindred type of electric propulsion for surface ships help the submarine engineer, since the development of the propulsion of the submarine, in most part, simply implies the combination, in a proper relation, of well known mechanical principles otherwise successfully applied.

An electric installation for surface propulsion has been successfully used in the United States Naval service in a large Navy collier, and one of the new battleships is to be so driven. The conditions on board a submarine are different in some particulars, but the same general principles may be said to apply.

Submerged Propulsion.

The most important developments in this feature of the submarine are in the types of motors, the system of control and the types of batteries.

Ventilated motors of the interpole type tend towards a logical development.

Our best controller manufacturers have given much time and attention to designing and building efficient, compact and reliable control apparatus.

Up to date, the conventional pasted or Plante type of lead cell has been the approved form of battery. So far, the efficiency of this type of battery has not been improved on. This type of battery, however, has the drawback of comparatively short life and the more or less theoretical one of deleterious gassing.

The gassing drawback is, with the most modern type of unit cell construction, more theoretical than real, and when

the batteries are properly installed and ventilated, no trouble need be expected with this feature. The question of life reduces itself largely to one of cost.

Two propositions for providing batteries of greater life are now available: the Iron-clad cell, a special construction of the lead battery, giving superior performance characteristics and greater life than the regular lead cell, but entailing greater first cost; and, the Nickel-iron or Edison cell, which has unquestionably greater life, but a cost greater than that of the lead cell.

A favorite proposition as to submerged propulsion has been the running of the engines installed for surface propulsion for submerged work also. Apart from the technical difficulties that exist in the way of doing this, it is somewhat problematical whether it is wholly desirable, if it can be done.

Such a system is only of advantage if the radius and speed submerged are greater for a given weight and space than is the case with the present system of dual propulsion. If, for a given weight and space, the radius and speed are only equal to the present system, or indeed only slightly greater, one should consider that the system has the following disadvantages:

(a) Noise submerged, permitting the presence of the submarine to be detected and her direction and distance, at least approximately, to be fixed by the enemy.

(b) Necessity for leaving a wake due to exhaust from engines, by which the course and speed of the vessel can be traced.

(c) Probable less reliability than the present system of submerged propulsion by battery and motors, which, while expensive in cost and in weight, is after all, within its limits, the most reliable part of the present day submarine.

PERISCOPES.

Being, as they are, the eyes of the vessel and hence one of the most important auxiliaries, developments in periscopes are of primary importance.

The optical principle of a submarine periscope is, roughly speaking, that of two astronomical telescopes facing one another in such a way that the upper one reduces the image, whilst the lower one magnifies it again in the same or slightly

higher degree. The object of this is to narrow down the required large field of view sufficiently, so that it may pass through the long narrow tube. At the top of the periscope, a prism or reflector is placed, in order to deflect rays from the horizon into the vertical tube, and a similar reflector at the bottom of the periscope deflects the rays into the eye of the observer.

In the latest submarine periscopes, an additional small telescope, of a Galilean type, is placed on both sides of the head reflector, for the purpose of changing the magnification. This small Galilean telescope is thrown in or out of the course of rays according to the magnification desired.

At suitable points of the instrument, strong glass plates are placed which serve the purpose of keeping the tube watertight and protecting the boat, in case the projecting part of the periscope should become damaged. The outside diameter of the tube is usually 5 in. and the length varies from about 17 ft. to 23 ft., according to requirements.

Today, considerable attention is being given to this subject by the more prominent optical companies, both in the United States and abroad, with distinctly beneficial results. The earlier progress in this line, it is true, was fostered by the submarine builders, but it requires a degree and character of ability and experience that can be afforded only by an organization doing a considerable volume of optical work rather than the making of a few sporadic periscopes.

The present day periscope has overcome many of the objections of the earlier type, such as lack of power and definition, inversion of image, etc., and a range finder attachment is a feature of all modern periscopes.

At present, it is the practice to fit each boat with two periscopes. There would seem no inherent objection to increasing this number in the larger size of boats, and this would tend toward greater assurance of the power of vision, since the chance of simultaneous destruction of all periscopes would be reduced. A greater number would add somewhat greater resistance to propulsion and would add to the cost, and for other purposes than increased insurance of vision, would at present seem to be unnecessary.

A suggestion has been made, and seems not impossible, to permit replacing a damaged periscope by a fresh one from within the hull.

SPECIAL FEATURES.

Certain special features have been advanced from time to time for use in submarines, and, as is usual in the case of such special features, have, until now, met with small approval. Some of these are now recognized as being of importance in some forms of operations, and while not perhaps so essential in the fleet seagoing type as in the coast defense type, are worthy of note.

By means of bottom wheels, the submarine may convert itself into a form of sub-aquatic automobile, slow it is true, but still sure and capable of operating on any character of bottom, except perhaps the very softest mud.

The vessel can give itself a small amount of negative buoyancy (virtual weight) and so be freed from the disconcerting influence of currents and wave and swell motions, as is the case with a submarine suspended between top and bottom in shallow water. This form of disturbance is troublesome to the British boats operating off Heligoland in the present war.

Operating on the bottom, she can approach cautiously a mined area and in conjunction with the diving compartment, from which she can send out a diver in any depth up to say 175 feet, she can slowly but certainly make her way through any mine field known.

In the conditions that have obtained in the present war, it seems not too much to say that the British submarines, so fitted, would have permitted the British to do as Mr. Winston Churchill threatened, "dig the Germans out", and in the absence of this feature they have at the time this was written been able to do nothing against the Germans.

SIGNALLING.

The only three essential features in which the submarines today may be said to be somewhat deficient are in sight and hearing and, in a sense, power of speech, or ability to signal.

The question of sight has been discussed above, and is solved fairly well by the periscope. As to hearing and signalling, considerable progress has also been made.

Already some years ago, the submarine bell signal had reached a considerable degree of development, but its range was limited and its speed but slow. The Fessenden Oscillator has provided a means for materially greater speed of signalling and somewhat greater range.

A sound and direction indicator is now available, and the development of greater facilities in this and kindred directions is in progress.

STRENGTH.

One of the great handicaps to accomplishment in submarine design is the necessary weight that must be given to the hull to permit it to withstand the pressure of submergence.

It has been customary abroad to design for a test depth of 40 meters, allowing, of course, a suitable factor of safety. In the United States, the test depth has been 200 feet.

Even considering all the accidents of various kinds that have befallen submarines, the writer is unaware of any that has hinged directly on this question, and a considerable penalty is imposed on the designer by the use of a test depth of 200 feet instead of, say, 150 feet.

STABILITY.

The advent of the seagoing type is going to introduce some new questions of stability, largely due to the increased size and the more severe conditions this type must be designed to encounter.

A suitable reference to present approved practice on submarines and surface torpedo craft should provide ample information as to the necessities in this respect.

ANTI-SUBMARINE PROVISIONS.

Today, no paper on submarines would be complete without at least a brief reference to the steps that may be taken toward defense against the submarine.

Considering the surface ship or fleet of ships as the object to be attacked, the provisions that may be made against damage

from submarine attack may be briefly of two kinds, (1) external to the object attacked, (2) contained within the object attacked.

Under head (1), we may consider (a) the aeroplane.

In certain waters, such as those of the Mediterranean or Gulf of Mexico in fairly smooth weather, it has been possible to detect the presence of the submarine, but even when so detected the aeroplane, due to its speed, is seldom able to do more than communicate with the ships and warn them. A dirigible, under suitable weather conditions, might be able to direct a bomb attack on the submarine, but its effectiveness would be doubtful.

Aerial attack on a submerged submarine is, so far, not dangerous.

(b) The fast moving tender, such as the destroyer. In some respects, this has so far been the most efficient means of protection, but its virtue is limited to cases where it can detect the submarine's presence on the surface, or near the surface, with periscopic exposure, and attack it by gun fire or ramming due to its proximity to the surface.

The press reports contain descriptions of pound nets planted by the British for catching German submarines. No accurate information is available as to their effectiveness, but even if effective, they can only be so locally.

Under head (2) we have (a) speed and handiness of the attacked ship, which together are of immense assistance in avoiding the attack of submarines. Both these qualities, if provided, are to a large extent incompatible with the present lumbering type of dreadnaught battleship. Further, this means of defense makes the battleship a fugitive from the submarine, and it is doubtful if it would be availed of by a fleet engaged in battle; i. e., it is mostly only useful to ships acting singly.

(b) Nets. An external protection of doubtful value, a serious handicap to speed and mobility, but without which no battleship at rest is quite safe.

(c) Structural provisions in the form of compartmenting, internal armor, compressed air installation for ejecting water, etc., are necessary, but in all probability no such provision will

prevent the temporary withdrawal from the combat of any unit that has received torpedo damage, and all such provisions can be largely nullified at will by minor changes in the submarine's weapon.

A few years ago the submarine designer was looked on largely as a creature of fantastic imagination. Today, he need make no apology for his wares, unless it be for his inability to keep pace with the growing demand and growing possibilities of his product.

The submarine is a tried and proven weapon of war, and with proper use and development, may be looked to to have as much effect on naval warfare and the types of naval ships as any other step in the whole history of naval development.

DISCUSSION

Naval Constructor Howard.

Naval Constructor H. S. Howard, U. S. N.,* wrote that, generally speaking, German submarines are a double-hull type and should more accurately be classed with the French and Italian types, instead of with the single-hull type of the United States and England.

He thought the use of the long-range torpedoes advocated by the author, fired at a formation with the chance of hitting a single ship, would not represent the most effective use of the submarine. He stated that battleships can fire torpedoes from long range at a formation on the chance of hitting any ship in the formation; that submarines should get in close enough to use a single target and fire from a range as close as possible. Torpedoes on submarines receive hard handling, he said, and a rugged, medium-range, accurate-running torpedo with large explosive charge would seem to be best suited to their use.

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Paper No. 206

SUBMARINE TORPEDO BOATS.

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INTRODUCTORY.

At the beginning of the Russo-Japanese War, 1904, the modern submarine was just entering the active phase of its development. At the outbreak of the war, Japan possessed no submarines. Five were ordered during the war and were shipped from the United States in knockdown condition and assembled in Japan. The readiness of these vessels for active service, however, was coincident with the opening of peace negotiations, so that they were afforded no opportunity for active service. For practical purposes, the Russian navy in the Pacific was in the same condition, although a few boats of small tonnage were transported by railway during the war across Siberia to Vladivostok. During the latter stages of the war, these vessels were in commission based at Vladivostok, but as no naval attack was delivered by the Japanese in this vicinity, the boats were never engaged. At the close of the war, the impression of the general public and even of the better informed engineering profession was that the submarine had failed to justify its existence. The truth was that it had not been tested. That this fact was clear to those in control of the building programs of the various naval powers was shown by the continuance of submarine construction by the pioneers in this field, viz., the United States, France, England, and Russia, and by the additions of submarines to the programs of Germany, Austria, Japan, Italy, Holland, Sweden, Norway, Denmark, Chile, Brazil, Portugal, Turkey, Peru and Greece. Dur-

ing the current year, the Spanish Navy authorities have made provision for a very respectable flotilla, the construction of the first units of which has already begun.

At the outbreak of the present war, the most important submarine flotillas were in the hands of England, France, the United States, Germany, Russia and Italy, and all of the important types so far developed were represented in the flotillas in these countries. Reliable data are lacking as to the exact numbers in commission in the navies of the warring powers at the outbreak of the war. Approximately, however, the numbers were about as follows:

Great Britain	75
France	55
Russia	25
Japan	13
Germany	32
Austria	6

Many of these, however, were old boats of very small displacement and unfitted by lack of speed, radius of action, armament, habitability, etc., to play effectively any role except that of local defence. For instance, so far as is known, all of the British submarines up to and including the "C" class have been employed solely for coast defense, thus leaving only the "D" and "E" classes available for such active operations in enemy waters as have been possible under the conditions obtaining. Thus, these operations have been carried out with a flotilla numbering at the beginning of the war only about twenty vessels. Similarly, about half of the original German flotilla was not suitable for operations at any great distance from its base. The conditions of the war, however, have afforded objectives for these boats, which have been lacking to the corresponding classes of English submarines, and the presence of hostile vessels within their effective radius has enabled them to contribute materially to the damage inflicted upon the British navy. It may be remarked in passing that such an outcome is always to be expected, that is to say, that in any naval war, the submarines of the weaker power will be afforded many more opportunities for striking successes than those of the

stronger power, since sooner or later the latter must necessarily undertake operations in waters rendered dangerous by hostile defensive submarines. In the case of the Anglo-German struggle now raging, the losses of the British navy, important as they have been, have certainly been much minimized by the fortunate geographical position of Great Britain, which enables her to contain the inferior German fleet with a minimum of risk to her capital ships. Under different and less favorable geographical conditions, the losses would have been materially increased, as the containing operations could not have been rendered effective without acceptance of corresponding increased risks.

CONSTRUCTION DURING THE WAR.

Since the beginning of the war, the information available with regard to new construction in the warring countries has been very much restricted. It is known that shipbuilding efforts in all the countries involved have been redoubled and that, in addition, the Allies have had submarines constructed outside of Europe. The number of vessels added to the flotillas of each power is a matter of pure conjecture. It is, however, reasonably certain that no important new developments have been made in the countries at war, for while a considerable number of vessels have undoubtedly been completed and commissioned, there has been no time for extensive experiments or developments, so that the new boats are undoubtedly duplicates of those already built, with only such minor changes as have been found desirable to facilitate rapid construction. At the outbreak of war, there were under construction in England and France, and probably in Germany, experimental underwater boats of very large displacement, up to 1200 tons on the surface. These so-called "fleet" submarines are intended to accompany and operate with the capital ships, and hence must necessarily have a high surface speed, a large radius of action, and great habitability. The successful production of such a vessel at the present time involves the solving of many complex engineering problems, and for such work, war conditions are eminently unsuitable. It is considered likely, therefore,

that the war will delay this development in Europe rather than hasten it. In fact, it is known that in some cases the work has been put aside in order to hasten the production of the fully developed but smaller types.

MAIN TYPES AND DISTRIBUTION.

The main types of submarines now in existence are the so-called Holland boats, built from the plans or under the patents of the Electric Boat Company, with the vessels built by Messrs. Vickers, Limited, and the Whitehead Company as modifications; the Laubeuf boats, the Germania or Krupp boats, and the Laurenti boats. Practically all of the vessels in the navies of Great Britain, the United States, Japan, Holland and Denmark are of the first type, which type is also employed extensively in the Russian service and, to a certain extent, in other countries. The Laubeuf type finds its largest representation in the French navy, and has also been supplied to Greece and Peru and is represented in the Japanese navy by two vessels now under construction. The Laurenti type finds its largest representation in the Italian and Swedish navies. This type has also been acquired in small numbers by Great Britain, the United States, Brazil, Denmark, and Portugal. Practically all the German flotilla is of the Germania or Krupp type, constructed either directly by the Krupp firm or by the Government at the Danzig dockyard. This type also forms the main part of the Austrian and Norwegian flotillas and is represented on a small scale in the navies of Russia and Italy. The characteristic differences between these main types are nearly all confined to the form, arrangement and construction of the hull and the location and capacity of the ballast tanks.

Owing to the advertising policy of the various designers and firms responsible for the development of the different types, considerable confusion exists with respect to the distinctions between the different types and the resulting effects of the differences upon the qualities of the boats. It, therefore, seems desirable here to discuss briefly a few of the points with respect to which confusion exists.

SUBMARINES AND SUBMERSIBLES.

These terms had their origin in France toward the close of the last century and were used to distinguish two quite separate types of under-water boat. As the differences between these two original types were very pronounced, the two terms had very definite meanings and could be used without confusion. The earliest French "Sous-Marins" were designed almost entirely for use under water and were supplied only with an electrical plant for propulsion. These vessels had no heat engines and were thus not capable of independent cruising and recharging the electric accumulators. The hulls were of spindle form, and as at all times they could be propelled without access to the atmosphere, the capacity of the ballast tanks was very small, since no necessity existed for any material amount of buoyancy when running on the surface. In fact, at their lightest draft, these vessels were nearly awash.

Subsequently, the French designers added heat engines to the power plant of this type so as to increase the radius and to render the boats autonomous. The surface buoyancy, however, was not materially increased. Insufficient buoyancy and freeboard, for the form and proportions chosen, resulted in poor qualities for surface navigation, which defect has come to be generally accepted as characteristic of the "Sous-Marin" as distinguished from the "submersible".

The submersible, on the other hand, was, as the term indicates, a vessel capable of cruising on the surface and which could, when desired, be submerged. To accomplish such results, a material reserve of buoyancy must be provided for surface operation and the vessel must be equipped with heat engines for surface propulsion and recharging of storage batteries. The double power equipment appeared first in the Holland vessels, the "Plunger" and the "Holland". The hulls of both these vessels were of the spindle form, but their reserve of buoyancy was greater than that of the French "Sous-Marin". Owing to this fact and to a difference in proportions, the nautical qualities were quite different from those of the

''Sous-Marin''. In these designs, however, about equal importance was attached to the surface and submerged qualities and it was not until the ''Narval'', from the designs of M. Laubeuf, appeared in France in 1900 that the term ''submersible'' came into use. In this vessel, the greatest importance was attached to those features of the design which were intended to improve the navigation qualities on the surface, and therefore the reserve of buoyancy allowed was relatively very great. The form of the vessel also differed materially from that of the ''Sous-Marin'', and also from that of the earlier Holland designs. In fact, the form of the ''Narval'' closely approached the ordinary ship form. The difficulty of constructing such a ship form of sufficient strength to safely withstand the pressures due to submergence was cleverly avoided by fitting an interior hull of circular section, the space between hulls being utilized for water ballast. The exterior hull, owing to its light construction, was incapable of withstanding high pressures, and, consequently, the ballast spaces between hulls were left in free communication with the sea when the vessel was submerged, thus throwing the pressure load on the inner hull.

As was to be expected, this vessel did not suffer from the characteristic defects of the French ''Sous-Marin'' in surface qualities.

As above mentioned, the earliest Holland design was intermediate between the French ''Sous-Marin'' and the ''submersible'' with respect to surface buoyancy. With regard to form and hull construction, however, it resembled the ''Sous-Marin'' rather than the ''submersible''. In the course of development of the type derived from the ''Narval'', the percentage of the surface buoyancy has been decreased. On the other hand, in the development of the Holland type, the percentage of buoyancy has been increased, so that the difference in practice in this respect is not now of material importance. As a matter of fact, the percentage of buoyancy necessary to secure satisfactory surface qualities is not a constant, but varies with the form of the vessel, the speed-length ratio, the length-beam ratio and other factors.

Owing to the demonstrated superiority of the French "submersible" over the French "Sous-Marin", the designers and builders of under-water boats have generally preferred to have their product classed as "submersibles" rather than "submarines", a fact which does not serve to clarify the situation. As indicated above, so far as qualities of modern vessels are concerned, the terms are practically without meaning. The demand for a boat primarily designed for submerged work only has disappeared and with it the type represented by the French "Sous-Marin". All modern boats are submersibles in the broad sense that they are vessels with the necessary qualities to enable them to operate on the surface efficiently and safely, while at the same time they preserve the power to submerge at will. So far as design and construction are concerned, the terms as generally used have more definite meaning, "submersible" being used to designate those types having ship-shape form of hull, while "submarine" is used to designate the types having a form of hull more nearly like the spindle of revolution.

SINGLE AND DOUBLE HULL TYPES.

Whether or not the terms "submarine" and "submersible" are destined to be perpetuated as descriptive of the two principal general types of under-water craft so far developed remains to be seen. There is in evidence now a tendency to replace these designations by the terms "single hull" and "double hull". In the former, the main ballast tanks are internal, being located within a strong outer hull, which, in section, is in the main part circular or nearly so, although it generally takes the form of ellipses forward and aft, and is sometimes somewhat elliptical throughout. All or a good portion of the water ballast is disposed within this strong hull, being contained in tanks whose internal walls are, in modern practice, sufficiently strong to withstand the pressure due to submergence with the flood valves open. In some cases, notably the Krupp design, a watertight superstructure is utilized to accommodate a good proportion of the ballast. The internal

walls of the inside ballast tank are often worked as double bottoms, so that in wake of the tanks a double hull exists in fact, but as the inner walls of the tanks are not continuous, there is no complete inner hull. In the double-hull types, on the contrary, there is a more or less complete strong pressure-resisting internal hull which is surrounded by an external hull of lighter construction, the greater part of the water ballast being accommodated in the space between the two hulls. The extremes of these two types are best represented, the double hull by the Laubeuf type, and the single hull by the modern Hollands; but between the two there are some constructions difficult to classify, on account of the extensive use made of the watertight superstructure embracing the pressure-resisting hull as illustrated by the Krupp type. Again, in one of the types for which the author is responsible, the double-hull construction is employed throughout the amidship portion of the vessels, with single-hull constructions fore and aft.

These different methods of construction all have their advantages and disadvantages. The use of the superstructure for ballast purposes gives an increase of surface buoyancy at little cost in increased size or material, but reduces the metacentric height when submerged, on account of the additional top weights involved. The use of a complete double hull gives excellent protection against damage, but the great extent of the tanks fore and aft necessitates their subdivision into a large number of separate compartments, to prevent excessive decrease in stability when the tanks are only partially filled. When this subdivision is carried to extremes, the venting and flooding arrangements of the tanks become unduly complex, and it is very difficult, if not impossible, to concentrate the control of these important operations. The combination of double hull amidships with single hulls forward and aft permits grouping the main ballast tanks amidships and using large tanks without great sacrifice of stability, while at the same time the greater part of the vessel is afforded adequate protection against the effects of collision.

When a ship-shape exterior form is desired, a double hull or partial double hull construction is practically a necessity;

whereas when a modified spindle form is satisfactory, the single hull construction is more suitable. The ship-shape exterior form has generally been considered more favorable to surface speed, but experience seems to show there is little to choose between the two forms in this respect. When the speeds are moderate, that is to say, when the speed-length ratio is suitable and the proper proportions are chosen, the modified spindle form seems to drive as easily on the surface as the ship form. On the other hand, the spindle form appears to be somewhat more satisfactory for submerged propulsion, so that other things being equal, this type generally shows a higher submerged speed. When adequate buoyancy is provided, there seems to be little if any choice between the two forms in the matter of behavior in a seaway. The ship form, when driven at relatively high speed, appears to be drier, but on the other hand, the spindle form appears to have an easier rolling motion, due principally to its more moderate surface metacentric height. In stanchness and safety the two types are equal.

The double-hull type is more difficult and costly to build, and unless very carefully designed, requires a greater proportion of available weight to be devoted to the hull. When the double hull extends over a considerable portion of the length of the vessel, the two hulls towards the end are apt to be in very close juxtaposition, which leads to difficulties in the construction. For very large vessels, where a high, surface sea speed must be maintained, the double-hull type would seem to be the most suitable; for small vessels, the single-hull type is apparently indicated; while for moderate-sized vessels, equal results may be obtained with either type.

DIVING AND EVEN KEEL SUBMARINES.

In the early days of submarine development, the boats were often designated as "diving boats" or "even-keel boats", the terms being supposed to be descriptive of the manner in which changes in depth of submersion were accomplished. The diving boats were controlled by stern rudders only, and changes of level were effected by inclining the axis of the vessel. The

even-keel boats were supposed to secure change in level without inclination of the axis by the employment of vertical thrust derived from inclining planes so disposed as to bring this thrust in the same transverse plane as the center of buoyancy of the vessel. Theoretically, it should be possible to submerge and control the depth of a body having a slight positive buoyancy by this latter method, but in practice the forces tending to produce fore and aft inclinations are always present and it is absolutely essential to provide means for controlling them. This is universally done by horizontal rudders. In modern practice, horizontal rudders are generally fitted both at the bow and at the stern. These are sometimes combined with one or more sets of inclining planes or hydroplanes. Strictly speaking, all modern submarines are diving vessels, as the bow is always slightly depressed during the operation of submerging.

PRINCIPAL FEATURES OF DESIGN.

There is, in the design of a submarine, an even greater number of conflicting elements than in the case of other vessels, and a submarine is always a compromise. In some cases one element is somewhat exaggerated at the cost of another, to suit particular conditions, which is justifiable; but too often the naval boards of the various powers require the impossible. Because one vessel has been built with great surface speed and another with great submerged speed, it does not follow that a vessel can be built which will successfully combine the two. And the same holds true with armament, radius of action, etc. Perhaps the best way to obtain an idea of what may reasonably be demanded of a submarine, at present, is to take up a number of items, such as size, reserve buoyancy, habitability, speed, armament, etc., and investigate the conditions in regard to each at the present time.

Size.

Size is usually determined mainly by the amount of money available for construction, except in cases where some particular local need is to be met, as in the case of Denmark, Holland, and some other small powers whose only aim is to defend a short coast line, for which purpose small vessels are quite suit-

able. For such purposes, vessels of 200 to 300 tons have been built in considerable numbers. From this displacement practically all sizes up to 800 tons surface displacement can be found, and still larger types have been laid down. The larger vessels are designed to operate at long distances from their base, and for extended periods. The intermediate sizes are the results of the gradual development of the submarine (each power carrying on its lists numbers of vessels several years old) or of lack of funds to build the larger types. At the present stage of development there seems, except in special cases, little reason for the construction of vessels between the harbor and coast defense types of 300 to 500 tons surface displacement and the sea-going type of 800 tons up.

Habitability.

Habitability is strictly a function of size. After the necessary machinery has been placed in the hull, what space is left over is assigned to the crew for quarters. In the smaller coast-defense vessels, this space is quite restricted, but as they should operate from a base, this objection is not serious. In the large sea-going types, accommodations of some comfort are an absolute necessity, if the endurance of the crew is to equal that of the vessel, and there is noticeably a tendency to devote considerably more space than formerly to the use of the crews and officers.

Armament.

The armament carried by a submarine is more nearly independent of the size than in any other type of vessel. Increase of size has not, in the past, been accompanied by commensurate increase in armament. The main, and until recently, the only weapon of the submarine is the torpedo. For the smallest vessels now likely to be built, 300 to 400 tons, it is quite feasible to install four tubes in the bow; in the largest vessels under construction, it is impossible to install more in this, the most efficient position. In the large boats, two stern tubes also can be installed, but they are of somewhat dubious utility, because, aside from the uncertainty of the torpedo following the direct line of sight, due to eddies and propeller race, they can be used only against a vessel astern, which is not likely to be a very common mode of attack.

In vessels of small displacement, internal broadside tubes are impracticable. In larger vessels, these can be fitted, but they are open to serious objections on account of their interference with other vital important interior arrangements.

The above remarks have been limited to internal tubes, which are unquestionably much more efficient than external tubes or launching apparatus, since in the former case the torpedo is available at all times for inspection and adjustment, while in the latter case the torpedoes are accessible only when the vessel is on the surface. Exterior launching apparatus is very largely used in the French and Russian navies, but has not in the past found favor in other services. With the increasing size of the boats, however, there have recently appeared new forms of tubes for mounting on deck designed to fire torpedoes at any angle and for use either on the surface or submerged. If the large sea-going submarine is destined to replace the torpedo-boat destroyer, then it is quite certain that a heavy armament of this character will be carried, even if practical experience should show that such apparatus functions perfectly only when the vessel is on the surface.

As was said above, until comparatively recently, torpedoes were the only arm of the submarine. Most of the larger vessels now building are equipped with small guns of from about one- to three-inch calibre. These guns were first adopted in England and Germany, presumably for defense against small picket boats, but have, since the beginning of the war, been mainly used for attacking merchant vessels.

Buoyancy.

The reserve buoyancy of the modern submarine when on the surface with all ballast tanks empty will generally be found to be from 25 to 45 percent of the surface displacement, but in some exceptional cases a larger or smaller percentage exists. As indicated above, no absolute requirement can be laid down in this respect, as the amount necessary or desirable will depend upon varying features of design.

SPEED AND RADIUS.

While the surface speed and radius of the submarine are determined by the same considerations as for ordinary ships,

viz., the power and fuel consumption of the engines, the resistance of the ship and the fuel supply, the corresponding submerged qualities present some peculiar features due to certain characteristics of the electric power plant. The maximum submerged speed is, of course, fixed by the maximum power of the electric motors, and the corresponding radius by the capacity of the storage battery. If the total amount of energy obtainable from the battery were a constant at all rates of discharge, then the relation between any given speed and the corresponding radius would be fixed by the relation between this speed and the resistance. As a matter of fact, however, the amount of energy obtainable from the lead battery, almost universally used, varies with the rate of discharge, the total amount of the energy materially increasing as the rate of discharge is lowered. In consequence, the radius of any given boat increases very rapidly as the speed is lowered. For instance, for certain classes of United States submarines, the maximum speed is 12 knots and the corresponding radius is 12 nautical miles, whereas the radius at about five knots speed rises to 140 nautical miles. Again, if the battery be discharged to its safe limit of voltage at a high rate and the rate then be materially reduced, the voltage will rise and additional energy may safely be obtained. Consequently, after running out the full radius at high speed, the boat possesses a reserve radius at lower speeds. In the case above cited, this reserve amounts to about 35 nautical miles. In general, as the speed is a function of motor power, while the radius is a function of battery capacity, the submerged qualities of different designs can only be properly compared when both speed and the corresponding radius are known.

Obviously, owing to the necessity for a double power equipment, the speeds and radii on the surface and submerged are complementary to each other, and other things being equal, an increase in one can only be gained by a sacrifice of the other. No standard fixed relation between the two is as yet universally accepted, nor may this be expected, since the best combination of these antagonistic qualities is dependent on variable military considerations.

As the submarine has come into extended use, there has

been a continuous demand for increases in both surface and submerged speed, which has been met in the only possible way, viz., by increases in displacement. A general survey of the development in all countries shows that up to surface displacements of about 600 tons, there has been an increase in both surface and submerged speeds. With those displacements, submerged speeds of from 10 to 12 knots have been obtained, combined with a corresponding surface speed of about 16 knots. For the present, the development of submerged speeds appears to have stopped at about this point, and further increases in displacement are being devoted to increasing the surface qualities, the aim being to produce submarines of sufficiently high surface speed to enable them to operate with and as a part of the main battle fleet now composed of battleships, destroyers and scout cruisers.

That the increase in surface speed is an exceedingly expensive development is clearly shown by the fact that in the United States boats above referred to, a surface speed of 14 knots was combined with a submerged speed of 12 knots on a displacement of approximately 300 tons, whereas double this displacement has been required in Europe to obtain a surface speed of from 16 to 17 knots, even when combined with a submerged speed of only 10 knots. As the cost of construction and maintenance varies almost directly with the displacement, and as the submerged qualities and armament determine the value of the boats when the issue is actually joined, it is easy to see why the naval authorities of the United States did not follow the European tendency to constant small increases in surface speed and displacement, but have preferred, for coast defense purposes, to limit the surface speed to about 14 knots in order to increase the number of units available. When it comes, however, to the question of the fleet submarine, the conditions to be met in the various countries vary but little, and, in consequence, a more uniform practice in this respect may be anticipated. At the present writing, the minimum surface speed regarded as satisfactory for such vessels is 20 knots, but in some quarters even this is held to be insufficient, and speeds as high as 25 knots are strongly advocated. As matters now stand, the attainment of very high surface speeds is dependent

upon our ability to construct engines of very great power suitable for use under the peculiar conditions obtaining in submarines. This part of the subject will be treated more fully below.

SURFACE POWER EQUIPMENT.

At the present time, almost all modern submarines depend for surface propulsion on Diesel engines, the only exceptions being a small number of French boats equipped with steam engines. The Diesel engine is, in fact, the ideal motor for this purpose on account of the following qualities:

(a) Compactness and moderate weight.
(b) Great economy in fuel consumption.
(c) Ability to start instantly.
(d) Ease in disposition of products of combustion.
(e) Freedom from excessive radiation or storage of heat.

In all respects, except quality (a), the Diesel engine is vastly superior to the steam engine and hence is to be preferred.

The conditions under which any engine must work in a submarine are very unfavorable. The space and weight available are strictly limited and the demand for speed so insistent as to force the use of comparatively light-weight, high-speed engines. Complete reliability of operation under such circumstances can only be attained after an adequate period of development. The submarine Diesel engine, while a newcomer in the field, has even now been developed to a point where for moderate powers, entirely satisfactory reliability is obtained, when extremes in the way of light weight and high speed are avoided. The best engineering talent in all countries is being devoted to the development of these engines, which is in fact making rapid strides. Up to the present time, the maximum power per unit which is actually in successful service is about 1200 horsepower, but considerably larger units are under construction. As is natural, owing to the short time in which this type of engine has been under development, uniformity of practice has not been reached. In Germany, and in other Continental European countries except France and Russia, very high-speed, light-weight engines are most in favor, with the

two-cycle type generally predominating over the four-cycle, although many of the German boats are equipped with four-cycle engines constructed by the Augsburg Works, the others being equipped with two-cycle engines constructed by the Krupp and Nuremberg Works. In France and Russia, both two- and four-cycle engines are employed and there is a tendency towards the use of engines of greater weight and more moderate speed. In England, the two-cycle engine has not found favor. Practically all of the English boats are equipped with four-cycle engines of moderate speed and weight. No effort appears to have been made to gain a slight increase in surface speed by the use of the lightest possible engines. In the United States, both two- and four-cycle engines have been installed, and in a number of cases the two-cycle engines have been of the high-speed, light-weight type. The tendency now is towards the use of a heavier engine of more moderate speed, a development which means an increase in the displacement of the boats in order to avoid a loss of surface or submerged speed.

The lightest Diesel engines so far employed weigh about 50 pounds per brake horsepower and operate at a speed of about 500 r.p.m. The heaviest engines weigh about 100 pounds per horsepower and operate at a speed of about 350 r.p.m. A fair average for single-acting engines of substantial construction and moderate speed may be taken as 70 pounds per horsepower. While future developments will no doubt result in some decrease in weight without sacrificing durability or reliability, there is no reason to believe that the improvement will be radical, so that to meet conditions more severe than those now prevailing, a change in type of machinery will be necessary.

In the present stage of development of the single-acting Diesel engine, it is entirely practicable to install a submarine power plant of from 4000 to 5000 horsepower in a boat of from 900 to 1100 tons surface displacement, thereby attaining a surface speed of 20 knots. For a speed of 25 knots, however, from 8000 to 12,000 horsepower would be required, and this, for the present, is generally considered beyond the capacity of the Diesel engine as so far developed. It follows that notwithstanding its serious disadvantages for submarine service, submarine designers may be forced to employ steam plants in order

to meet the demand for a surface speed of 25 knots or more. The use of such steam plants, however, is not likely to be permanent. They are certain to be displaced by Diesel engines as soon as the development of the latter permits it. Because steam units have been developed for other purposes to powers in excess of those required for fleet submarines, it is often assumed that there will be no great difficulty in adapting the steam engine to submarine propulsion. In the author's judgment, this is an erroneous assumption, since, as a matter of fact, the adaptation of the steam drive to the requirements of the submarine involves many a step in the dark, and the attempt is likely to result in many disappointments. In fact, it is not beyond the bounds of possibility that the effort may result in complete failure, in that while the speed may be obtained, other and vital military qualities may be sacrificed to such an extent as to make it impossible for the vessels to perform the service for which they are designed.

SUBMERGED POWER AND EQUIPMENT.

Storage batteries and electric motors are now invariably used for propulsion submerged. Such equipment is in the following respects absolutely ideal:

(a) The weight of the plant remains absolutely constant while in operation.

(b) There is no evolution of heat while running submerged.

(c) The motors are silent and free from vibration.

All of these points are exceedingly important and each must be met in a satisfactory manner by any apparatus proposed for submerged propulsion. The disadvantages of the electric drive are as follows:

(a) Excessive space and weight required.

(b) Fragility and lack of durability of the storage battery under the adverse conditions of operation in the submarine.

(c) The element of danger arising from the hydrogen-oxygen gases given off by all batteries while under charge.

With horsepower rated at that necessary to maintain the maximum speed of the boat for one hour, a modern submarine electric plant will weigh about 265 pounds per horsepower. Obviously, this great weight added to that required for surface propulsion purposes militates against the attainment of very high speeds. Again, the arrangements which are necessary to secure safety and reliability in the operation of the battery are expensive with respect to space and weight, and involve restrictions on the freedom of design in other respects. In this connection may be mentioned the necessity for adequate insulation between the different cells of the battery and between the battery as a whole and the structure of the vessel, as well as the protection of the battery from mechanical damage and from salt water, and its adequate ventilation in order to prevent the accumulation of the oxygen-hydrogen gases generated while charging.

On account of the above disadvantages, considerable effort has been expended in the attempt to develop a substitute for the electric drive and particularly in the effort to produce a system which would employ the same prime mover for surface and submerged work. Of the various proposals made with this object in view, none has passed the experimental stage and many are foredoomed to failure, being based on wrong premises. The most promising system involves a closed circuit oil engine plant where the greater part of the exhaust gases are in continuous use, being supplied at the appropriate period in the cycle with the necessary components of fuel and oxygen. With this system only a slight quantity of excess gas is required to be discharged overboard, whereas with many other proposals, the whole of the exhaust gases is involved, a feature which is fatal to success. Some experimental successes have been obtained with the above mentioned closed circuit system and it appears likely that the mechanical difficulties remaining can be surmounted, at least for small units. All such systems, however, involving as they do now the use of reciprocating engines, have a serious military drawback, viz., owing to the vibrations set up in the hull of the submarine, its presence can probably be detected by the enemy at a consid-

erable distance, even if not revealed by the escape of surplus exhaust gases to the surface.

Up to the present time, practically all submarines have been equipped with lead-acid storage batteries, all operating on the same principle and differing only in details of design. The number of cells involved is usually 120, giving a nominal voltage of 240. Owing to the use of acid electrolyte, the containing jars are of hard rubber compound, or similar material. Such materials are not, by their nature, well adapted to withstand the stresses and strains to which they are sometimes subjected in service, and in consequence, there has been in the past more or less difficulty with storage batteries in service due to the failure of containing jars. As a result of experience, however, superior materials have now been evolved, so that today, in so far as reliability and safety are concerned, no serious objection can be taken to this type of battery. In the nature of things, however, the battery is short-lived, since the plates are only capable of a limited number of cycles of operation; and, moreover, in order to obtain the maximum service possible from the batteries, constant care and attention and fairly frequent overhauls are required.

Recently the nickel-iron alkaline cell developed by Mr. Edison has been introduced and many claims of superiority over the lead-acid type are made by its advocates. Adequate service experience with this battery on a large scale is as yet lacking, and until it is had, the relative merits and demerits of the two types cannot be definitely determined. In its original condition as developed for vehicle and other work, the Edison battery was inferior to the lead-acid battery with respect to energy output per volume of space occupied, and for this and other reasons it was entirely unsuitable for submarine use. The design, however, has now been changed with a view to overcoming the various objections previously existing and it is claimed that it is now at least equal to the lead-acid type with respect to space and weight occupied for a given capacity, while in mechanical strength and durability it is claimed to be greatly superior. Its first cost, however, is very much higher, which serves as a set-off from a financial point of view against increased durability. Reliability and

safety in service with large installations yet remain to be demonstrated.

LESSONS FROM THE PRESENT WAR.

The operation of submarines in the present war has emphasized their use in some directions and minimized it in others and has introduced one entirely new element, viz., their use as commerce destroyers.

The submarine was originally developed for harbor defence. When its capabilities had sufficiently increased, it was assigned to the larger role of coast defence, and with further development, it came to be considered as an aid to the high-seas fleet, as well as a useful weapon for independent offensive action in enemy waters.

As a coast-defence vessel, the submarine has had a very good test and has rendered excellent, although not spectacular, service. Though the British fleet very largely outnumbers the German fleet, it has been obliged to content itself with a waiting policy, and so far as is known, the main line of battleships has been held at a distance of some three hundred miles or more from the German coast. It is quite conceivable that the fixed defences of the German coast, including those at Helgoland, might prevent the English from ''digging out the German fleet''. It is also quite certain that the coast defenses and German battleships together could not force the English fleet out to any such distance as 300 miles. The loss of many cruisers in the North Sea in the early days of the war clearly revealed the hazards run by large ships in these waters. It is, therefore, fair to say that the submarine has up to this time been the main element in preserving the German coast from attack, even though Great Britain has in a broad sense undisputed control of the sea. This freedom of attack of the German North Sea coast, principally through its protection by submarines, is brought into greater relief by the history of the Allies' attack upon the Dardanelles. In this case, the fleet, although infinitely weaker than the main line fleet, massed against the Germans, was able to advance against and bombard the land fortifications and to cover the landing of very large bodies of troops. The fleet has also succeeded in main-

taining free communication with these troops. That a reasonable number of the coast defence type of submarine would have been sufficient to prevent these operations is obvious from the difficulties and losses experienced there since the arrival of one or two German submarines.

The usefulness of the larger type of submarines for scouting purposes has been demonstrated by the British operations in the North Sea, and their value for isolated offensive operations in enemy waters has been amply demonstrated by the success of the British boats in Helgoland Bight, the Baltic, in the Sea of Marmora; and those of the German boats in the North Sea, in the English Channel and the Atlantic.

With respect to the use of submarines in connection with the main battle fleet, the war so far tells us nothing except their value under certain circumstances for scouting purposes. Should a great naval action eventually be fought in a somewhat restricted area in the North Sea, it is not beyond the bounds of possibility that submarines may participate therein, notwithstanding the fact that none of the warring powers has as yet any boats especially designed for operation with the main battle fleet.

The most surprising feature of the war has been the extensive use of the German submarines as commerce destroyers. Of the legitimacy of this use, this paper is hardly the place to express an opinion, but it is obvious that if the attempt be crowned with any great successes, it will be necessary to provide for a like contingency in the case of any future war. It should be recognized that Great Britain's location and comparatively short coast line and immense commerce offer a very tempting opportunity for the Germans and it should also be remembered that at the beginning of the war Great Britain, like every other country, was totally unprepared with any adequate defence against the use of a submarine as a commerce destroyer. The only weak links in the German chain and the ones that have thus far prevented their campaign from having any decisive effect are the great number of ships entering and clearing the British ports daily and the small number of submarines the Germans have had available for this duty. On the whole, it may be said that while the results have not by any means

been decisive, the effort has been sufficiently successful to demonstrate the fact that the development of submarines as commerce destroyers must be regarded as a probability of the future.

In general, it may be stated that submarines of existing types have proved efficient in the work for which they were designed and that the history of the war indicates that in some respects their offensive possibilities were either unsuspected or underestimated.

In view of the wide range of usefulness of the submarine and the difference in the qualities required to efficiently perform the different duties to which it may be assigned, it may be confidently asserted that the submarine fleets of the future will be made up of at least two, and possibly three or four, distinct types, each especially designed for the particular duties assigned to it. For defensive purposes only, numbers are essential, and if the boats are to be provided in sufficient numbers to render the defence effective, if the coast line be extensive, financial considerations alone render it imperative that the displacement and cost be the minimum possible, while preserving the necessary offensive power. Such boats must, of course, possess the necessary seaworthiness and habitability to enable them to operate in all weathers off the coast, but they need not possess a high surface speed and heavy gun armament or a very great radius of action. On the other hand, the submerged armament, speed and radius must be well provided for. In other words, in these designs, emphasis should be laid upon the submerged qualities rather than the surface qualities. The principal role of this type is to render the coast inviolate, even if the enemy possesses control of the high seas, and this duty can, except in very special cases, be more effectively performed by large numbers of small vessels of moderate surface speed rather than small numbers of large vessels with high surface speed. The actual displacements and speeds necessary for the purposes will vary with the extent and configuration of the coast line, the nature of the approaches thereto, etc., and consequently no fixed limit for these qualities can be set down. Two varieties of this main type may appear, one designed for local defence and operating generally from a shore base, and

the other of somewhat larger displacement, with better sea-going qualities and operating generally from a floating base.

The other main type will be the submarine designed primarily for offensive action, operating either independently or in conjunction with the battleship fleet. If such vessels are to accompany the fleet, a high surface speed of at least 20 knots, and more if possible, is an absolute essential, also a radius of action and endurance approximating that of the battleships. Such boats must be sufficiently seaworthy to hold the seas in all weather and must be sufficiently comfortable to enable the crew to live on board for extended intervals without such hardship as would interfere with their efficiency. For use with the fleet only, the boat must be well armed with torpedoes and have as high submerged speed as is practicable, although a very great submerged radius is not perhaps an essential. For independent operation against a distant enemy, nearly the same qualities are desirable, although in this case the maximum surface speed is not so essential, while very highly developed submerged qualities are of greater importance, as is also the gun armament. This last set of qualities is also best suited for the submarine commerce destroyer. It will be seen then that the qualities required for the ''fleet'' submarine do not differ greatly from those best suited for commerce destruction and for independent offensive action, and it is therefore at least probable that some compromise between the conflicting demands will be effected and a single type thus be evolved to perform these three functions. In this connection, however, it should always be remembered that geographical considerations and the proximity of a possible enemy must naturally have their influence, so that the appearance of the successful fleet submarine does not necessarily involve the disappearance of the type already developed intermediate between the fleet submarine and the defence type. In other words, the European powers may well continue to build boats of some 600 or 700 tons displacement, combining a surface speed of 16 or 17 knots with a submerged speed of about 10 knots, since this type, under European conditions, is capable of effective offensive action in enemy waters, is useful as a commerce destroyer, and,

in addition, is not too large to play a defensive part when necessary.

Speaking generally, information with regard to the employment of submarines in the present war has been confined to the results achieved, so that as yet there is little if any data available bearing upon details of design. Nevertheless, one conclusion may be safely drawn from the war experience, viz., that it is folly to unduly sacrifice submerged qualities in favor of surface qualities, since it is abundantly apparent that the highest efficiency can only be obtained when the submerged qualities are so highly developed as to enable the submarine to operate for long periods submerged and yet be able at any moment to attain a high speed for purposes of attack.

Paper No. 207

PRESENT CONDITION OF THE SUBMARINE.

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CHAPTER I.

THE BEGINNINGS OF SUBMARINE NAVIGATION.

It is known that the first submarine boat worthy of the name was built in the United States. This was the "Tortoise of Bushnell", which, in 1776, attacked the English frigate "Eagle" near New York.

Nevertheless, more than a century elapsed before the submarine began to enter into the composition of war fleets, notwithstanding all the attempts made during the course of the 19th century, and of which a certain number are of marked interest. It will suffice to mention the names of Fulton, Bauer, Bourgois and Brun, Nordenfelt, Baker, Waddington, etc.

It was in France that the military submarine first appeared. This was the "Gymnote", built according to the designs of the French Naval Engineer, Gustave Zédé, after the ideas of the celebrated engineer, Dupuy-de-Lôme, the creator of armored fleets.

The construction of the "Gymnote" was ordered in 1886. Launched September 24, 1887, trials were run during 1887-8, and for the first time the essential problem of submarine navigation, that is to say, underwater navigation at a stated depth with a path regular and under control, was solved in a truly practical manner, and justifying the statement that a new branch of the art of marine construction was about to open.*

At the conclusion of the successful trials of the "Gymnote", of 30 tons displacement, the French Navy started con-

* The "Gymnote" formed part of the French fleet until 1905.

struction, in 1890, on the "Gustave Zédé", of 270 tons displacement. This vessel was launched in 1893. At the same time, the experiments of Holland and of Lake were proceeding in the United States, and also those of Pullino, in Italy. The "Pullino", a little experimental submarine of 15 tons displacement, was launched in 1892, and later, the submarine, "Delfino", of 95 tons, was launched in 1894.

It is well to recall that in 1888 the Admiralty of the United States had opened a competition, following offers presented by Nordenfelt, Holland and Baker, offers which had not been accepted by the Government.

Fig. 1. The "Narval", the First Submersible of the Laubeuf Type (1897).

After the competition of 1888, which brought no definite results, a contract was entered into on May 3, 1893 with the Holland Company for a submarine named the "Plunger", which was to be propelled by steam power on the surface and by electrical power when immersed. The boat was not launched until August 7, 1897. The trials of this boat were not successful and it was replaced by the "Holland", ordered in 1897 and launched in 1898, which was the first submarine in the Navy of the United States.

In its turn, the French naval authorities opened a competition, in 1896, for the construction of submarines.

All of the boats thus far mentioned belong to the early type of the submarine. In consequence of the French sub-

marine competition, there appeared a submarine boat of a new type called "Submersible".

The first submersible was the "Narval", offered by me in competition in 1897. Its construction was ordered in 1898. It was launched October 21, 1899, completed its trials in July, 1900, and formed part of the French fleet until November, 1908.

As there exists much confusion between the two types of boat, it will be desirable to specify here their essential points of difference.

CHAPTER II.

THE TWO TYPES, SUBMARINE AND SUBMERSIBLE.

It has been often said, and wrongly, that the submersible is distinguished from the submarine of earlier type, because it has two motors, one for running on the surface and the other for running immersed. It is true that in France the "Narval" was the first boat destined for underwater navigation and provided with two motors. The submarines which had preceded had but a single motor, a motor of the electric type with storage battery, with a consequent serious reduction in the radius of action. But two motors may be placed on the submarine of earlier type, as has been done. This is what was done particularly in the United States by Mr. John Holland, in 1893, on the "Plunger" (a steam engine and an electric motor) and, in 1897, on the "Holland" (a gasoline engine and an electric motor).

The differences between the submarine of earlier type, or the submarine pure and simple, and the submersible are rather differences in mode of construction, reserve of buoyancy and form of body.

(1) Mode of Construction. See Plate I. With the submarine pure and simple, the water ballast tanks (or tanks intended to submerge and trim the boat in the submerged condition) are placed inside the boat, which has circular cross-sections. With the submersible type, these reservoirs, of much greater volume, are placed outside the hull proper. There results an entirely different mode of construction. The submer-

sible has a double shell. The inner skin, which must resist the pressure of the water, is made of thick plates. The shape of the sections is not circular, but elliptical. The outer skin, which is only subject to the pressure of the water when the ballast tanks are empty, that is to say, when running on the surface, is made of very light plates, as in torpedo boat construction. The double hull may be complete, as in the case of the "Narval", or partial, as in later examples of the same type.

(2) **Reserve Buoyancy.** If the term reserve buoyancy is given to the emerged volume of a boat navigating on the surface, this volume, in the case of ordinary ships, is approximately equal to the immersed volume. In many cases it is even greater. If we denote by the term coefficient of reserve buoyancy the ratio of the reserve buoyancy to the total volume of the ship completely immersed, this ratio, which is at least 50 percent for ordinary sea-going ships, was no more than 3 to 7 percent for the earliest submarines, and scarcely exceeds 12 or 13 percent for the submarine type pure and simple. It is much greater for the submersible type. The boats built according to my designs have 27 to 33 percent. The "Narval" had even 41 percent.

It results from this important difference that the submarine pure and simple, low in the water and with small reserve buoyancy, readily drives into the waves, and that on the open sea it soon becomes necessary to withdraw the crew from the exterior and to close all openings. The boat then navigates on the surface under the same conditions as if immersed. The submersible, on the other hand, navigates under such conditions exactly like an ordinary ship. The difference regarding comfort of living and fatigue of the crew is considerable.

The French manoeuvers of 1902 with submarines of the type "Morse" and submersibles of the type "Sirène", of 150 tons; the comparative trials, in 1905, between the submarine "Z" and the submersible "Aigrette", of 180 tons; and, finally, the manoeuvers of 1909 between submarines type "Emeraude" and submersibles type "Pluviose", of 400 tons, have definitely demonstrated that the submersible type possesses nautical qualities far superior to the other.

(3) Form. A difference no less considerable exists in regard to the external form. The submarine pure and simple is distinguished by circular sections, and for many years it has been given a pointed form at both ends; similar, in general, to the cigar, the classical form for boats of this type. It was the general opinion, furthermore, that this form would alone permit of diving under good control. When, in 1897, the design of the "Narval" was presented, in which the external form was exactly similar to that of a torpedo boat, many persons (and especially officers acquainted through experience with underwater navigation) expressed the opinion that a boat thus formed could never dive satisfactorily. Experience alone could determine the question. It has proved, in effect, that the submersible type is as well suited to diving as the other.

The most serious objection to the submersible type, at the beginning, was that in order to pass from the condition of surface navigation to that of underwater navigation, a change must be made from the heat prime mover to the electric motor; and then a considerable volume of water must be taken in between the double shell of the hull in order to annul the very considerable reserve of buoyancy. But during the time thus required, the boat was in a critical condition, permitting destruction by the ship of an enemy without the chance of escape.

In point of fact, on the "Narval", at the beginning of the trials, the time required for immersing reached 28 minutes and the objection noted above was fully justified. But on this same boat, with the progressive training of the crew and after some changes, this time was reduced successively to 20, then to 15 and finally to 12 minutes. On the "Sirène" type of 1900, which followed, the time required from surface navigation to underwater navigation was reduced to 8 minutes; on the "Aigrette" type of 1902 to 6 minutes, and, finally, on the submersibles of the "Pluviose" type of 1905, to less than 5 minutes. The objection formerly made has, therefore, no further significance; a period of 5 minutes answers all military requirements.

The diagrams of Plate I, in connection with the present note, show plainly the difference of construction between the "submarine" and the "submersible".

In order to establish the priority of the invention and of the construction of the submersibles in France, it will suffice to note the following dates:

The "Narval" was launched October 21, 1899.

Four French submersibles of the "Sirène" type ("Narval" type modified) were launched as follows: May 5, 1901; July 13, 1901; September 7, 1901; October 29, 1901.

The "Protector", of Mr. S. Lake, was launched November 1, 1902.

The "Glauco", the first Italian submersible after the designs of Engineer Laurenti, was launched July 9, 1905.

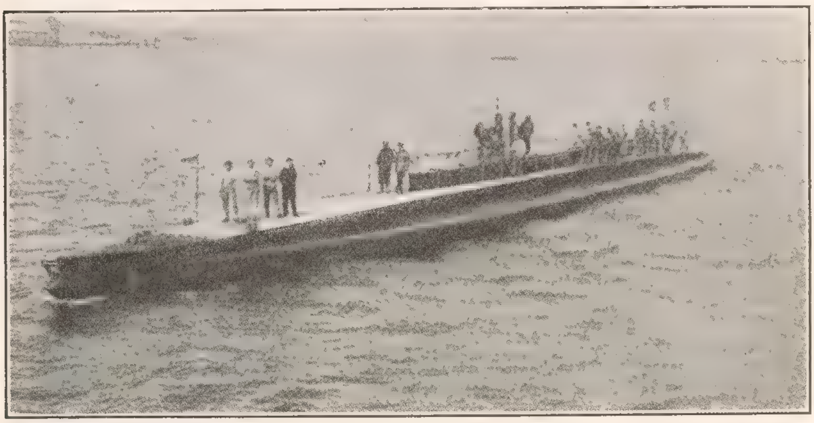


Fig. 2. French Submersible "Foucault", Laubeuf Type (1905).

The "U-1", the first German submersible, built by the Germania-Krupp Co., was launched August 30, 1905.

In 1900, France was the only naval military power possessing submersibles. All the other naval powers were building only submarines of the earlier types.

Since that time the submersible type has made great progress. In France, the comparative trials, mentioned above, demonstrated the superiority of the submersible. Since 1907, only submarine craft of this type have been built, and the submarines pure and simple of earlier construction, to the number of 39, have been gradually retired. There remained, on January 1, 1915, no more than 7 of these in service.

The submersible type has been adopted, exclusively, by Germany, Italy, Greece, Sweden, Norway, Portugal and Brazil.

Other naval powers are developing experimentally the submersible and the submarine: England, United States, Russia and Japan.

Finally, the submarine type pure and simple is undergoing modification and is approaching, little by little, to the submersible.

For example, the American firm which has built, either directly or through its licencees, the greatest number of submarines pure and simple, the Electric Boat Co., has long built boats of small reserve of buoyancy. This company is now turning to the submersible type, as is shown by the following table of the boats which it has already constructed or which it has under construction:*

	Displacement Surface	Displacement Submerged	Buoyancy, percentage of submerged displacement
Type "Holland" (1897)	62	70	11%
Type "Adder" (1900)	106	122	13%
Type "Viper" (1904)	148	170	13%
Type C ("Octopus"), 1904	238	273	13%
Type D ("Narval"), 1907	285	337	15%
Type E ("Skipjack"), 1908	310	370	16%
Type F ("Carp"), 1909	350	430	18.5%
Type H ("Seawolf"), 1910	375	475	21%
Type K, 1911 (last type in service)	390	520	25%
Type L (1912), building	650	950	31.5%
Type M (1914), building †	1000	1500	33%

It thus appears that the reserve buoyancy of the submarine built by the Electric Boat Co., first small in value, has steadily increased, especially since 1908, when the superiority of the submersible type had been well established in France.

Finally, this firm, which, until 1913, built submarines with a single shell and with water ballast tanks inside, is now building a new type M with large reserve buoyancy and with a partial double shell. This is a marked change toward the submersible type, and I believe that I am justified in a feeling of

* See Engineering, Nov. 17, 1911.

† See Motor Ship and Motor Boat, April 16, 1914.

deep satisfaction at the success of the ideas for which I have stood during the past 18 years.

CHAPTER III.

PRESENT DEVELOPMENT OF SUBMARINE NAVIGATION.

At the present day, practically all naval powers have adopted the policy of building submarines. In order to measure the progress made during the past few years, it will serve to recall that on January 1, 1901, the situation was as follows:

France: 5 submarines and 1 submersible completed; 4 submarines and 4 submersibles under construction. Total, 14.

United States: 1 submarine completed ("Holland"); 7 submarines under construction (type "Adder"). Total, 8.

England: 6 submarines under construction (5, H-1 to H-5 and A-1).

Italy: 2 submarines completed ("Delfino", "Pullino").

The remaining powers had nothing.

On January 1, 1914, according to the table published by the English Admiralty, which we here complete for the smaller

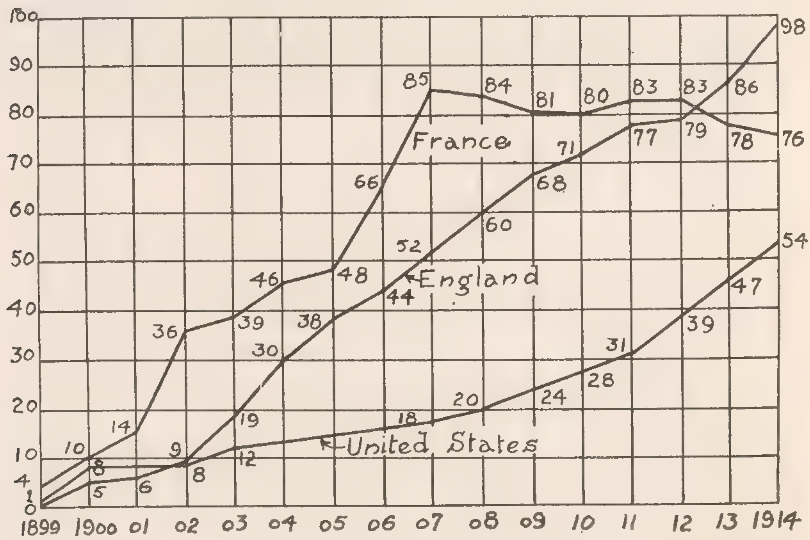


Fig. 3. Number of Submarines Built and Under Construction for Each Year, 1899 to 1914 Inclusive. France, England and United States.

powers, the number of submarines built or under construction is given in the following table. (See also Schema, Fig. 3.)†

Name of country	Built	No. of submarines Under construction	Total
England	69	29	98
France	50	26	76
United States	29	25	54
Russia	25	18	43
Germany	24	14	38
Italy	18	2	20
Japan	13	2	15
Austria	6	5	11
Denmark	6	4	10
Sweden	5	3	8
Holland	5	3	8
Norway	3	2	5
Greece	2	2	4
Brazil	3	0	3
Peru	2	0	2
Chili	0	2	2
Portugal	1	0	1

It appears that the total number of submarines of the various types, built or under construction on January 1, 1914, reaches the very considerable figure of 400. The naval powers without submarines are easily counted. Spain and Argentina are almost the only maritime powers which have no submarines in their fleet.

† The drawing, Fig. 3, accounts for submarines lost or out of commission. The number of submarines out of commission is very large in the French navy, because it was the first one to consider a large flotilla of submarines, and for that reason it was compelled to make a large number of experiments and to construct a variety of types of vessels. These attempts have been taken advantage of by many other navies, which later on accepted submarine navigation as a fact. The submarines out of commission in the French navy total 34, whilst there have been only 7 in England and one in the United States. Furthermore, all the submarines of the Class A in England and the 7 of the Adder type in the United States should at the present time be put out of commission.

If, instead of charting the number of units, the total tonnage had been charted, there would be a very noticeable increase to the credit of France; in fact, for the two years 1912-13, 26 small submarines, of a total tonnage of only 3400, were placed out of commission, and 19 submarines, of a total tonnage of 16,500, have been placed on the ways—7 of them of 1250 tons each.

Among these 400 boats, the prevailing types are as follows:*

Type of Submarine Pure and Simple.

1. Electric Boat Co. (United States). At the close of 1911 this firm counted 56 boats to its credit, making an aggregate of 18,361 tons displacement in full immersion, built either directly or under license for the United States, England, Russia, Japan, Austria, Holland, Denmark and Chili. During the years 1912 and 1913, this firm has doubtless added several thousand tons to this figure.

2. Vickers & Co. (England). This firm has built for England, Austria and Japan, altogether, 90 boats, aggregating about 30,000 tons. The first boats were built from the plans of the Electric Boat Co. (type H-1 to H-5), and later, from its own designs (types A, B, and C), and finally, in collaboration with the engineers of the British Admiralty (types D, E, and F).

There should be added to these boats the 14 submarines of the Vicker's type built by the Chatham Navy Yard (6 of type C, 2 of type D, and 6 of type E), together some 7250 tons.

Submersible Type.

1. Laubeuf Design (France). From my own plans there have been built in the national arsenals 43 submersibles for the French Navy, at the works of Schneider & Co. (Le Creusot, France), 11 for various naval powers, and at the works of Sir William Armstrong, Whitworth & Co., at Newcastle, 4 for the English Admiralty, altogether 58 boats aggregating about 29,000 tons.

To these should be added the submersibles built by the French Admiralty according to this system, but after the detailed plans of other engineers (Hutter, Simonet), after I had retired from the service of the State. These reach 26 in number, of which the aggregate displacement amounts to about 22,000 tons, because 9 of the number have a total submerged displacement exceeding 1000 tons each.

2. Germania-Krupp Design (Germany). The Germania-Krupp Co. had completed or had under construction on January 1, 1914, 37 submersibles for Germany, 7 for Austria, 5 for

* These figures are given with due reserve, the various naval powers holding in secret definite information regarding their submarine fleet.

Norway, 3 for Russia, 1 for Italy, altogether 53 boats, of about 30,000 tons. These figures comprise the submersibles built by the Imperial Arsenal at Dantzig, according to the Germania-Krupp designs in collaboration with the German Admiralty.

3. **Societá Fiat San Giorgio (Laurenti Design) Italy.** This company has built 14 submersibles for Italy, 4 for England, 1 for the United States, 2 for Germany, 4 for Sweden, 3 for Brazil, 1 for Denmark, 1 for Portugal; altogether 30 boats, with

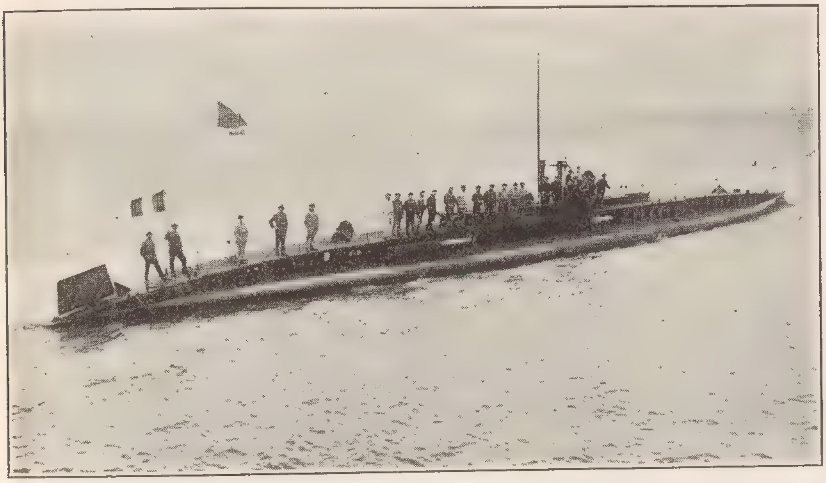


Fig. 4. The Submersible "Brumaire" (1906).

an aggregate displacement of only about 10,000 tons, most of the boats being small in size.

The various other designs:

Lake (United States), Boubnoff (Russia), Richson (Sweden), Bernardis (Italy), Cavallini (Italy), Romazotti (France), Maugas (France), etc., are represented by only a much smaller number of boats and of tonnage displacement.

CHAPTER IV.

INCREASE IN DISPLACEMENT.

Submarines have not escaped the tendency, which makes itself so strongly felt, towards increase in displacement.

It may be asked if, in their case, this tendency is quite justified.

In passing from 15,000 to 25,000 tons or more, armour-plated ships have had their speed, and particularly their offensive power, increased. The same remark applies to all ships whose principal armament is the gun.

But ships which have the torpedo as the sole or preponderating offensive armament do not find such marked advantage in an increase of displacement.

If we take, for example, the French destroyers, the following table may be established:

Displacement	Speed	Armament
Type of 330 tons	28 to 30 kts	1 gun of 65 mm (2.56 in) 6 guns of 47 mm (1.85 in) 2 torpedo-tubes
Type of 475 tons	28 to 30 kts	6 guns of 65 mm (2.56 in) 3 torpedo-tubes
Type of 750 tons	30 to 33 kts	2 guns of 100 mm (3.94 in) 4 guns of 65 mm (2.56 in) 4 tubes mounted in pairs.

It will be seen that while the speed has increased, the armament in artillery has also perceptibly increased (not in the number of units, but in power). The armament in torpedoes (all of 18 in.) has not increased so much, two coupled tubes not being worth much more than three independent tubes.

The same remark may be made with regard to submarines.

Here it may be said that the torpedoes form the sole armament, the two small guns which have been placed on certain of these vessels being of very little use, except against cargo or passenger steamers.

In France, the "Narval", of 120-202 tons, and the small submersibles of the "Sirène" type, constructed after my plans, in 1898 and 1900, had already four outer torpedo-launching arrangements for 18 in. torpedoes.

This number had been increased to six, in 1904, in the submersibles of the "Circe" type, of 350-490 tons, and to seven (of which one is an inner tube), in 1905, in the "Pluviose" class, of 400-550 tons, and in 1906, in the "Brumaire" class of the same displacement.

It remains the same on the "Clorinde" class (building) of 410-560 tons, on the "Archimède", of 575-810 tons, and it has

only been increased to eight, of which two are inner tubes, on the "Gustave Zédé", of 800-1100 tons, launched in May, 1913.

In England, the C class, of 280-314 tons, has but two tubes; the D class, of 550-615 tons, but three.

In the United States, all the submarines of the Electric Boat Co., from the D class (285-335 tons) to the K class (390-520 tons) have four torpedo tubes each.

Hence, it will be seen that the offensive power of submarines has increased very little, notwithstanding an enormous increase of displacement.

Efforts were made especially to improve the speed and the radius of action, both when on the surface and when submerged, for the first submarines were, it may well be said, quite insufficient in this respect.

The following speeds were obtained (or expected):

France.

Ships in Service.

No.	Name	When Launched	Displacement Surf. (Tons)	Displacement Sub. (Tons)	Speed Surf. (Knots)	Speed Sub. (Knots)
4	Sirène type*	1901	157	210	10	6
2	Aigrette type†	1904	177	250	9	6.5
2	Circe type†	1907	350	490	12	8
18	Pluviose type*	1908- 9-10	400	550	12.3	8
16	Brumaire type†	1910-11-12	400	550	13	9
1	Archimède type*	1911	575	810	15	10
	Ships in Course of Completion.					
9	Clorinde type†	1913	412	560	15	9.5
3	Bellone type†	1914	520	780	17	9.5
9	Gustave-Zédé and Dupuy-de-Lôme types*†	1913-14	800	1100	19	11.5
	Great Britain.					
13	Class A	1904-5	180	205	11	8
11	Class B	1904-5-6	280	314	12	8.5
38	Class C	1906-7-8-9	280	320	13	9
8	Class D	1908-12	550	615	14	10
16	Class E	1912-13-14	730	825	16	10

* Steam engines. †Diesel motors.

And if my information is correct, Class F (displacement 950-1200 tons), now in the course of construction, is expected to reach 19 knots on the surface and 12 knots submerged.

To sum up, it will be seen that for submarines, the increase of displacement provides but a rather feeble increase of offensive power, and that to obtain the greatly augmented speeds, it is necessary to pass to large displacements.

On the other hand, it may be said that a large displacement offers serious drawbacks for a submarine, as follows:

(a) Greater difficulties of evolution while submerged.

(b) Too great a draught of water in the condition of navigation on the surface, as well as in the submerged condition. The draught of water in surface navigation does not allow them to pass in small depths; the draught of water when submerged prevents them passing under the keel of an enemy's ship (a necessary manoeuvre if the submarine, when attacking, finds itself too near the ship it aims at).

(c) Too large a turning circle, on the surface and submerged. This is of very great importance.

(d) Too high cost. The experience gained in naval manoeuvres, as well as in actual war, shows that a great number of submarines is necessary; and this becomes impossible, especially for the minor Navies, if the cost of each is too high.

These considerations lead to the conclusion that it is preferable to have two distinct types of submarine.

CHAPTER V.

FIRST TYPE: DEFENSIVE OR COAST-GUARD SUBMARINE.

These boats will have a moderate tonnage, good manoeuvring powers, a small turning circle, moderate draught, and, in consequence of their not being expensive, they can be constructed in rather large numbers. These ships must be well armed, but they need not realise very great speeds nor have a very large radius of action when navigating on the surface.

This class of submarines exists almost everywhere. It is represented:

In France, by the "Pluviose", "Brumaire", "Clorinde" types of 400 to 412 tons on the surface, 550 to 560 when submerged.

In the United States, by the C, D, E, F, G, H, K, classes of 238 to 390 tons (surface), 273 to 520 tons (submerged).

In Great Britain, by the classes B and C of 280-314 tons.

In Germany and Austria by the type "U-2" of Germania-Krupp, of 240-300 tons.

In Italy, by the type "Foca" of Laurenti, of 245,300 tons.

These latter types have too low a displacement. This class of submarine must, as a matter of fact, not only defend the coasts, but also take the offensive within a fairly large radius from the base of operations. They must, therefore, have good armament, excellent nautical qualities and good quarters for the crew, all of which is very difficult to obtain with a small tonnage.

Accordingly, they must have a high reserve buoyancy.

In the table of Chapter IV, it can be seen that in the submersibles of the "Pluviose" and "Brumaire" classes, laid down in 1905-1907, the reserve buoyancy is 150 tons, or 27% of the submerged displacement.

In the United States, this percentage is increasing more and more from the C class (14%) to the K class (25%).

In the British submarines, the buoyancy is only 11 to 12.5 percent of the submerged displacement. I have no hesitation in stating that this buoyancy is inadequate to give the ships good nautical qualities.

The good sea-going qualities of submersibles with large reserve buoyancy have been proved by a great number of journeys of long duration made by ships constructed after my plans, and of which I shall mention but a few.

The "Papin" ("Pluviose" type) went, in October, 1909, from Cherbourg to Bizerta. Of this journey, the passage from Rochefort to Oran, or 1230 sea-miles, was made in six days without putting in, at an average speed of 9 knots, notwithstanding two days of very bad weather in the Bay of Biscay and one day of mist to the south of Spain.

The "Brumaire" made the voyage from Dunkirk to Bordeaux, in the month of July, 1912, or 800 miles, in seventy-two hours without calling at a port, at an average speed of 11 knots.

The "Faraday", from September 28th to October 5th, 1912, made the passage from Rochefort to Toulon, or 1730 miles, without putting in, at an average speed of 11 knots, notwithstanding two days of bad weather. This latter trip constitutes, I believe, a record in distance covered by a submarine without putting in at a port.

It is conformable to an analogous programme that the two submersibles "Delphin" and "Xiphias" have been constructed after my plans by Messrs. Schneider & Co. for the Greek government.

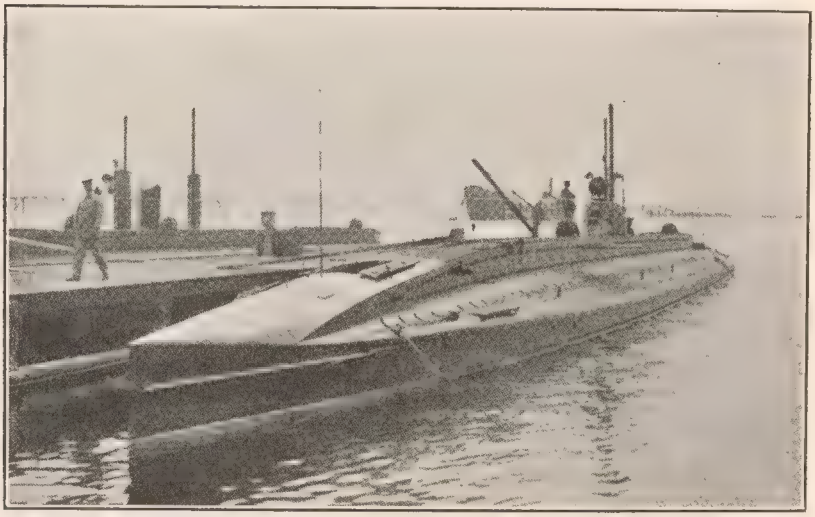


Fig. 5. Greek Submersible "Xiphias", Laubeuf Type.

In my last constructions, I augmented the buoyancy, with a view to further increasing the nautical qualities. Thus, these two boats have 310 tons on the surface and 460 tons when submerged, or a reserve buoyancy of 150 tons, about 33% of the submerged displacement. They yield 13.5/8.5 knots, and they are armed with one inner torpedo-launching tube and four outer tubes, with six torpedoes on board.

From September 30th, 1913 to October 5th, the "Delphin", without calling at any port and without being escorted, made the passage from Toulon, where she carried out her trials, to the Piraeus (or 1100 miles), at the average speed of 9.5 knots, with Greek staff and crew.

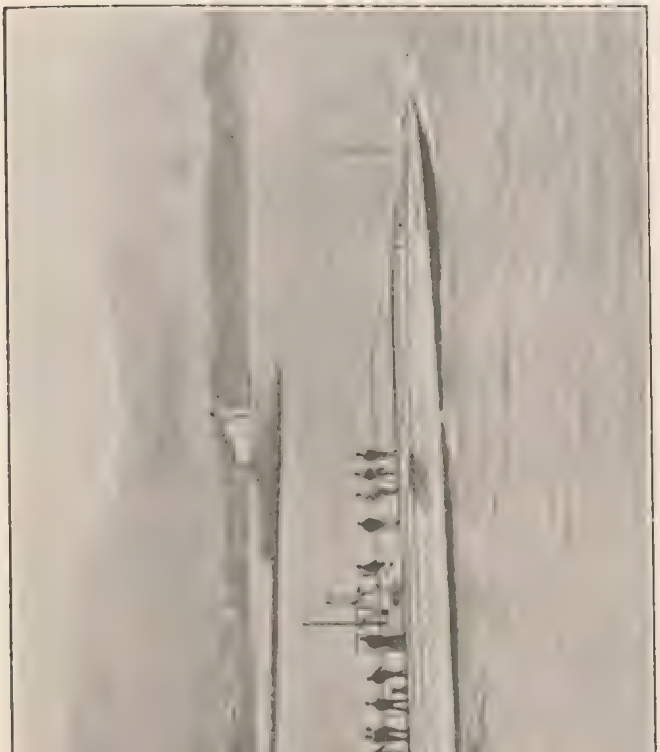


Fig. 6. Greek Submersible "Delphin", Laubeuf Type.

These two boats have a lesser displacement than the thirty-four submersibles of the "Pluviose" and "Brumaire" classes constructed for the French Navy. On the other hand, four other ships, which are building after my plans by Messrs. Schneider and Co. for the Japanese and Greek Navies, are a little larger. Their displacement is 460 tons on the surface, 670 submerged, or a buoyancy of 210 tons, about 31.5% of the submerged displacement.

These submersibles possess two inner tubes and four outer tubes, with eight torpedoes on board. They are to give 17/10 knots. The first was launched in Nov., 1913, the second in April, 1914. They are not yet completed, on account of the war.

CHAPTER VI.

SECOND TYPE: SQUADRON SUBMARINE.

The second type of submarine, which it is now sought to realise, is the high seas or squadron submarine.

The latter type, intended to accompany the fighting ships, to sail with a squadron in any weather, to take part in naval battles, must in future replace the destroyer type.

The enumeration of the operations in which it is to take part shows that it is absolutely necessary for this boat to possess high speed on the surface and good speed when submerged; a large radius of action, especially on the surface, great offensive power, good nautical qualities and excellent living quarters.

These are difficult conditions to fulfil, and can only be realized with a very considerable displacement.

It may be said at once that ships of intermediate tonnage, ranging between the coast-guard submarine and the squadron submarine, constructed or in course of construction, are useless: they are too large as coast-guard submarines, and too small as high-seas submarines.

I include in the number of these ships, which should never have been put down, all the submarines of 600 to 700 tons on the surface constructed or in the course of construction in France, in England (types D and E), in Germany (type U-21), in Russia, etc.

All these ships represent but half-measures. They cannot accomplish much more than coast-guard submersibles of 400 to 500 tons on the surface, they possess too low speed and inadequate nautical qualities to accompany a squadron on the high seas. They are likely to disappear before the submarine with great speed and of much greater tonnage.

Three types of submarine, only, approach closely, at the present time, to the true conception of the squadron submarine:

(1) The French Navy is in the lead: the "Gustave- Zédé", ordered in 1910, launched on May 20, 1913, is now commissioned. The "Nereide", ordered in 1911, launched on May 9, 1914, is completing. They have 800 tons on the surface, 1100 tons submerged. Two others, a little greater, were ordered in 1913 and five in 1914. They have 835 surface 1200 tons submerged.

(2) In Great Britain, the type F, of 950 to 1200 tons, ordered in 1912, is still on the slip. It is said that a new English type, the G, ordered in 1914, is greater; 1500 tons submerged.

(3) In the United States, a new type M, of the Electric Boat Co. is projected. The displacements are understood to be 1000 to 1500 tons.

If my information is correct, the programme of squadron submarines in France, Great Britain and the United States is similar: 19 to 20 knots on the surface, 11 to 12 knots submerged.

Will these types of submarine adequately represent squadron submersibles?

I answer, without hesitation: **No**, their speeds on the water and under the water are still insufficient.

To be able to accompany a squadron in any condition of the sea and take an effective part in a naval battle, it is necessary to have a maximum speed on the surface at least equal to that of the modern armoured ships, viz., 22 to 23 kts. I say "at least" because, as is well known, small ships lose much more speed than large ones in a heavy sea, and a submarine, even if it had 1000 tons displacement on the surface, is still but a small ship on the open sea.

It is necessary, also, for the squadron submarine to have a speed, when submerged for battle, at least equal to the current

speed of evolution of the armoured ships of the line at the time of the battle. And here a speed of 15 knots appears to me an absolute minimum.

Consequently, I say that, as long as submarine boats cannot attain speeds of 23 knots on the surface and 15 knots when submerged, they will be insufficient to fill the role of the squadron submarine and they will only impede armoured ships.

What now are the reasons which prevent the realization of these speeds at the present time?

(1) It has not yet been possible to construct very powerful internal-combustion motors, which would at the same time have a relatively small weight and size. If the immense progress accomplished in the last ten years in the construction of internal-combustion motors with four and two cycles is considered, one is led to believe that within a few years we shall have the necessary motors.

(2) The second point and the more weighty one, is the double motor. Besides the internal-combustion engine, the submarine has an electric ensemble consisting of motor and a battery of extremely heavy and cumbersome accumulators.

We are under a great debt to the electric storage battery. Without this, without the realisation of a source of energy which does not present variation in weight when delivering the accumulated energy, which absorbs neither air nor oxygen and discharges but few noxious gases, submarine navigation would perhaps not exist at all.

Today, showing ingratitude, we should like to banish the electric battery from the submarine and to place in these boats one motor only, supplying the necessary power for propulsion on the surface as well as when submerged.

Many attempts have been made in this direction, some with a single internal-combustion motor, others with a single steam-engine, but, up to the present time, no boat with a single motor has solved the very difficult problem which is before us. Searchers and inventors have, therefore, an open field before them. When they have given us the powerful, sure motor, with relatively small weight and size, which is so much desired by the builders of the submarine, the programme of squadron submarine set out above can be realised and the destroyer may disappear from modern fleets.

Till then we can only have, presumably, inaccurate approximations to a solution of the problem of the squadron submarine, and with very great displacement.

To sum up, the present tendencies of the constitution of submarine flotillas appear to be the following:

(1) Coast-Guard Submarines of moderate displacement, 350 to 500 tons on the surface, 500 to 750 tons submerged; well armed (for example, two inner torpedo-tubes, and outer-tubes or outer torpedo-launching equipment, with six or eight torpedoes on board); with suitable speeds (14 to 16 knots on the surface, 9 to 10 knots when submerged for battle); having a radius of action reasonably fixed in accordance with their probable operations and the geographical conditions of the country which they are to protect; having good living quarters; and, finally, with good nautical qualities, in order that they may be able to take the offensive within a fairly large radius, and this, in particular, implies a high reserve buoyancy.

(2) Squadron Submarines having a great displacement (without going too far, with a view to remaining within dimensions that do not create too serious difficulties of evolution or of use; for example, 1200 tons when submerged); having high speed (23 knots, at least, on the surface, 15 knots, at least, when submerged) with a powerful armament (for example eight inner torpedo-tubes and sixteen torpedoes on board); a very large radius of action on the surface; excellent quarters; and first-class nautical qualities, implying a high reserve buoyancy.

The conclusions which precede represent the ideas which I have defended for many years. (See, for example, a lecture given on Dec. 10, 1910, before the Ligue Maritime Française and an article on the submarine in the Navy League Annual, edited by Alan H. Burgoyne, M. P. for the year 1913-14.)

I have had the satisfaction of seeing these ideas adopted by the French Navy, then, in 1913, by the English Admiralty. Finally, since writing the preceding lines, I have received a copy of the report of the U. S. General Naval Board, of which Admiral Dewey is President, and which appeared in Dec., 1914. This report recommends the construction of two types of submarine, one for the high seas and the other for coast defence, and asks the building of 3 boats of the first type and 16 of the second, adding that no intermediate type seems to be called for.

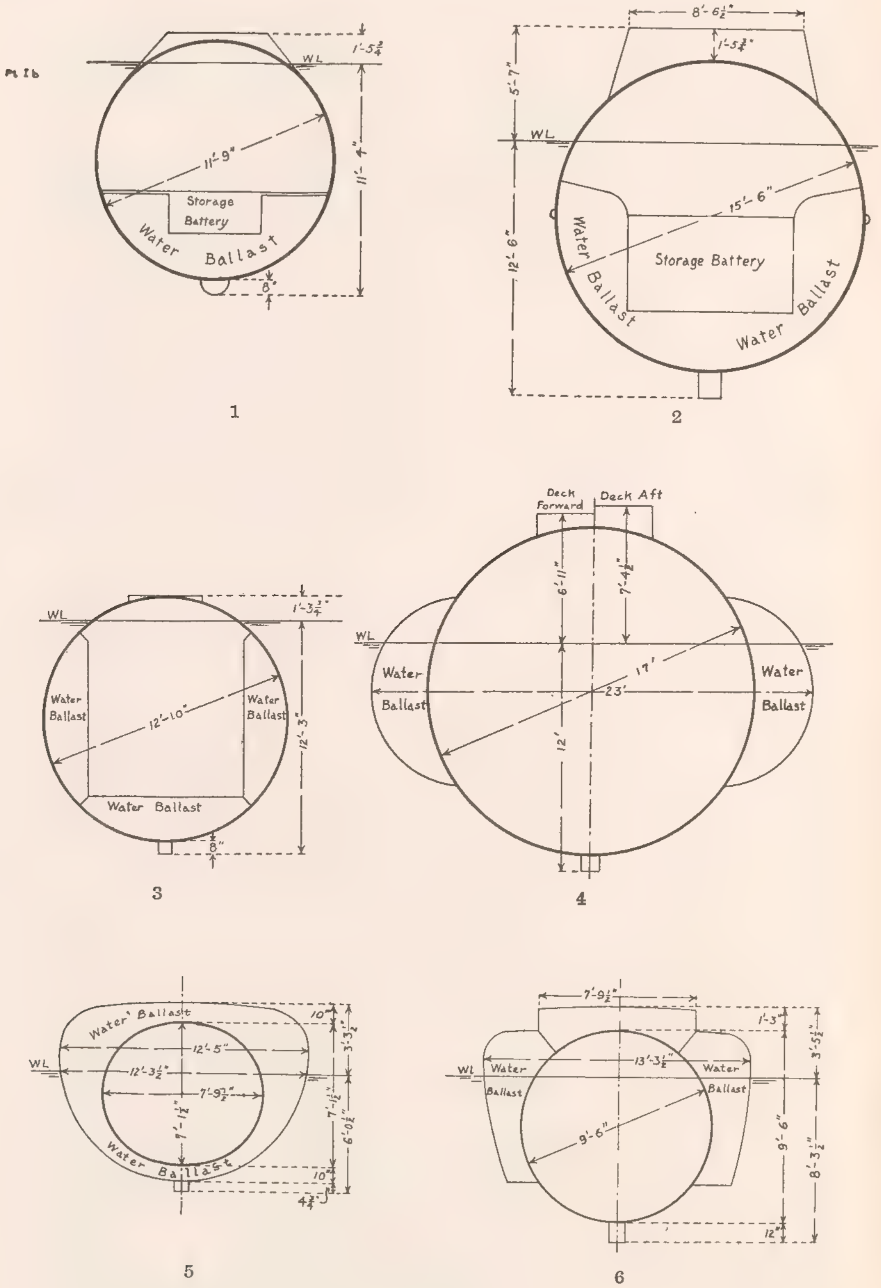

WL
1'-5¾"
11'-9"
11'-4"
Storage Battery
Water Ballast
8"
1
8'-6½"
1'-5¾"
5'-7"
WL
15'-6"
12'-6"
Storage Battery
Water Ballast
Water Ballast
2
Deck Forward
Deck Aft
6'-11"
7'-4½"
WL
1'-3¾"
Water Ballast
12'-10"
Water Ballast
12'-3"
Water Ballast
8"
3
Water Ballast
17'
23'
Water Ballast
12'
4
Water Ballast
10"
12'-5"
WL
12'-3½"
7'-9½"
3'-3½"
7'-1½"
6'-0½"
7'-1½"
Water Ballast
10"
4¾"
5
7'-9½"
1'-3"
13'-3½"
WL
Water Ballast
Water Ballast
3'-5½"
9'-6"
9'-6"
8'-3½"
12"
6

Plate I-a.

Plate I-a.

1 Submarine—Holland System.
Type Adder; launched in 1900.
Displacement, 108/122 tons.
Percentage of Reserve Buoyancy, 11.5.
Sections, circular.

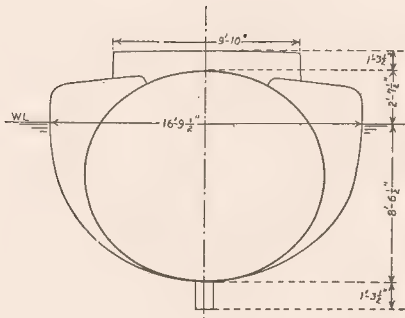
2 Submarine—Electric Boat Co.'s System.
Type K; launched in 1913.
Displacement, 390/520 tons.
Percentage of Reserve Buoyancy, 25.
Sections, circular.

3 French Submarine—Maugas System.
Type Farfadet; displacement 184/200 tons; launched in 1901.
Type Emerande; displacement 392/422 tons; launched in 1906.
Percentage of Reserve Buoyancy, 7 to 8.
Sections, circular.

4 English Submarine—Type E (Vickers)
Displacement, 720/825 tons; launched in 1912.
Percentage of Reserve Buoyancy, 13.
Sections, circular.

5 Submersible—Laubeuf System.
Type Narval.
Displacement, 117/202 tons; launched in 1899.
Percentage of Reserve Buoyancy, 42.
Double Shell complete; Sections, elliptical.

6 Submersible—Laubeuf System.
Type Sirène; launched in 1901.
Type Aigrette; launched in 1904.
Percentage of Reserve Buoyancy, 28 to 30.
Partial Double Shell; Sections circular.



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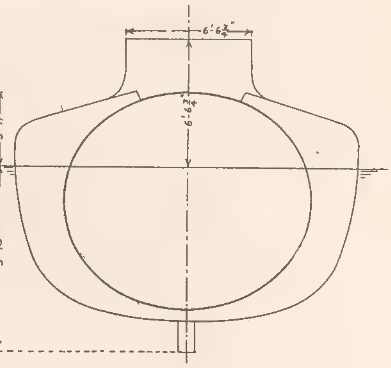

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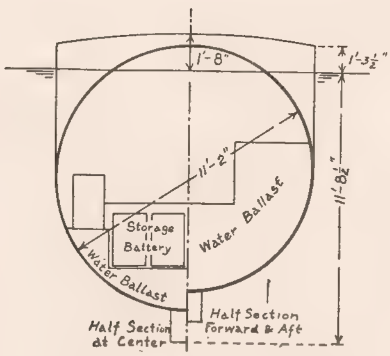

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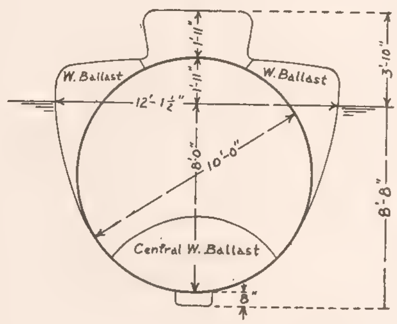

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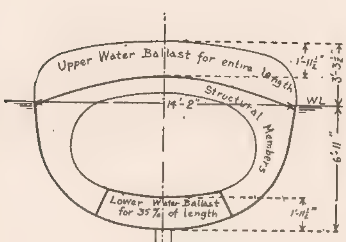

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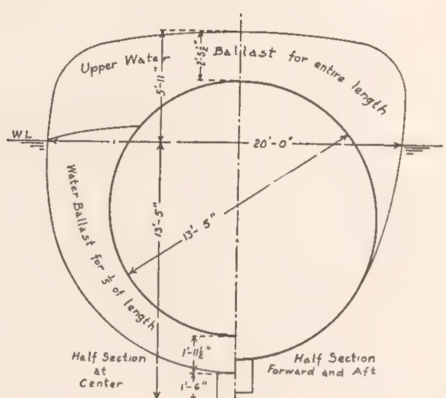

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Plate I-b.

Plate I-b.

7 Submersible—Laubeuf System.
Types launched in 1907-1910.
Percentage of Reserve Buoyancy, 28-30.
Partial Double Shell.
Sections, elliptical.

8 Submersible—Laubeuf System.
Latest types launched in 1911-1914.
Percentage of Reserve Buoyancy, 33.
Partial Double Shell.
Sections, elliptical.

9 Submarine—Lake System.
Type Protector; launched in 1902.
Displacement, 136/174 tons.
Percentage of Reserve Buoyancy, 22.
Sections, circular.

10 Submersible—Germania-Krupp System.
Type Kobben; launched in 1909.
Displacement, 202/255 tons.
Percentage of Reserve Buoyancy, 21.
Partial Double Shell; Sections circular.

11 Submersible—Laurenti System.
Type Foca; launched in 1908.
Displacement, 185/265 (with upper W. B.).
Percentage of Reserve Buoyancy, 30.
Partial Double Shell.

12 Submersible—Large Displacement—Laurenti System.
(Under Design according to Berling, 1912)
Complete Double Shell for 20% of length.
Partial Double Shell at ends.
Sections, circular.

CHAPTER VII.

THE MILITARY USE OF THE SUBMARINE.

The military role of the submarine, important as it is, has been long misunderstood.

In 1899, Mr. Goschen, first lord of the British Admiralty, questioned in the House of Commons by Mr. MacLaren, responded:

"The idea of the submarine is not sane. In a naval war the submarine is of no account".

Many admiralties at that time shared these views. Submarines were considered as "mosquito" boats, of no actual utility, put out of action in a moderate seaway. They were looked on as laboratory devices, incapable of rendering practical service.

The present war has served to give a resounding denial to these assertions. Submarines have shown in a conclusive manner what they really are, very effective means of offensive warfare.

It is now too early to attempt the history of their exploits. Only later, after the war, when the official reports of the belligerants will have become available, can such a history be written.

In 1907, in a note presented to the International Congress of Naval Architecture, held at the Exposition of Bordeaux, on the "Present and Future of Underwater Navigation", I said

"It seems to me plainly demonstrated that the use of submarines permits:

(1) The defence of coasts; the prevention of the bombardment of ports.

(2) The rendering ineffective of any attempt at blockade.

(3) The prevention of the anchoring of a squadron on the coast with attempt at disembarcation of a landing force.

(4) In restricted waters carrying the attack to the coasts of the enemy and giving his squadrons cause to fear, at each sortie or return, a torpedo attack difficult to avoid.

(5) Finally in European waters, and under certain conditions, cutting most of the maritime grand routes of commerce.

"The first three purposes may be realized indifferently by submarines pure and simple or by submersibles. The last two, on the contrary, can only be realized by submersibles, because for such ends it is absolutely necessary to have good sea boats, which the submarines pure and simple are not.

"The development of the submarine has led already, and will further lead, especially in the future, to important changes in naval politics, maritime construction, the constitution of the fleets of various States, especially of secondary powers. It will also bring important changes in strategy and naval tactics.

"In résumé, the submarine will assure, in the near future, the freedom of all coasts and even that of narrow seas. Further, it constitutes an arm of high morality, since it permits a feeble state to defend itself against a powerful enemy."

Already in 1898, I had written:* "The submersibles can take a bold offensive and carry the war into the waters of the enemy, even if this enemy has through his squadrons an overpowering superiority; even if the empire of the sea may be his without contest; they will enter the enemy's harbors in spite of the lines of mines and can there attack the ships which, believing themselves in safety, are engaged in taking on fuel, ammunition, etc".

Finally, in 1908, examining the possibilities of a war between England and Germany, I said:†

"How can Germany compensate for her numerical inferiority in armored ships? for this inferiority will always exist; whatever effort Germany may put forth, an English reply will oppose to the German armored ships, English armored ships in greater number and probably of greater power.

"For me, the key to the future German tactics is given by the appropriations assigned to submarines: 5 million marks in 1907, 7 million in 1908, 10 million in 1909, 15 million the following years.

"Germany is building, furthermore, not submarines pure and simple, of which the role is limited to the near defence of ports and coasts on account of their mediocre nautical qualities,

* The Submarine and the War Against England.

† Les Luttes Maritimes Prochaines (1908). This brochure has been translated into English under the title "Naval Supremacy, Who?"

but submersibles which permit taking the offensive in waters of moderate extent, such as the North Sea or the Baltic Sea. The published statement regarding the naval budget says, 'We shall build submersibles of large dimensions, the only type which can render the service which we desire from them!'

"The only submarine in service, the U-1, has a displacement of 240 tons. Those following have displacements of 300 tons. It is possible that with the appropriations to be expected, Germany may have 60 submersibles in 1915" (actually she has 40).

"Their role will be certainly to sail from German ports as soon as war is declared and to attack the English battleships on their own coasts. A few fortunate torpedo shots will re-establish the balance of the two fleets, and the German fleet can then dispute with the English the control of the seas and render free the passage for a disembarkment of troops in England.

"These are the tactics which I had developed for France when, at the time of the Fashoda affair, war seemed likely to develop between England and France.

"Today, I believe that I shall see my ideas applied from the other side of the Rhine".

But my opinions may have small weight, because I am the inventor and a builder of submersibles. I turn, therefore, from the exposition of my personal ideas to cite the opinions of various naval experts.

In 1800, Admiral Lord St. Vincent, examining Fulton's design for a submarine said, "Pitt is the greatest fool that ever lived to encourage those who are already masters of the sea in a useless type of war, and which, if it succeeds will deprive them of this superiority".

That was a clear vision of a future then far removed. Nearer in point of time, at the beginning of underwater navigation Lieut. (now Rear Admiral) Kimball in 1896 wrote:*

"From all the above it will appear that submarine boats owe their capability for usefulness to the fact that they can take cover in water as shore forces can in earth; that when so covered they have under certain conditions an offensive power

* "The Tactical Value of Submarines", by Lieut. W. W. Kimball, Army and Navy Register, January, 1896.

that cannot be neglected; that until their exact powers are gauged by experience they would accomplish much by affecting the *morale* of the enemy; that although they have a wide field of usefulness, they do not fill the places of battleships, cruisers, or fast torpedo vessels; and that they are especially needful to a country weak in numbers of armored ships when opposed by a strong naval power.

"This is true of submarine boats of offensive, defensive and manoeuvering powers that can be built today; but if their development in power parallels that of other fighting machines, their field of usefulness will greatly widen".

We realize today that the improvements made in the construction of the submarine justify the prophecy of Lieut. Kimball.

The French Admiral Fournier, on his part, wrote in 1910 as follows: *

"It is readily seen what an advantage the Russian fleet would have realized by the presence of only a half dozen submersibles of the "Pluviose" type at Port Arthur. Such a little flotilla, well commanded, would have sufficed to torpedo the best of Admiral Togo's ships, if need be on the open sea, thus giving to the Russian fleet the mastery of the sea, an end impossible to realize with their other ships, and thus changing the whole aspect of the campaign.

. . . . "The submersible torpedo boat, with large radius of action, is today the offensive submarine *par excellence.* In restricted areas it is the enemy most to be feared by the armored ship, because it can render itself invisible and remain invulnerable under water if it is well handled in its manoeuvers of approach and attack. It may thus come within striking distance with its automatic torpedoes and sink the armored ship at a single blow, or put it out of service at least for the remainder of the war.

"Submersible torpedo boats of this character, judiciously distributed in the waters of Europe, with the aid of numerous destroyers and of a few extra-fast scouts, would render such waters untenable for an enemy's fleet of the high freeboard

* "Naval Policy and the French Fleet", by Vice Admiral E. Fournier, 1910.

type, and would make impossible an attempt at bombardment, a blockade or disembarkation of troops; in short any hostile operation requiring mastery of the sea as a condition of success''.

Following are two English opinions:

Admiral Lord Fisher, in London in 1905, said to the French Admiral Fournier the following, reported by him in his book ''La Politique Navale'' (page 163):

''The intervention of the submarine brings with it a veritable revolution in the conditions of naval war''.

Finally, those interested, either directly or remotely, in the problem of naval matériel have not been able to ignore the resounding article by Admiral Sir Percy Scott, published in the Times of June 5, 1914.

It contains ideas which have appeared absolutely revolutionary to many naval authorities. Following are certain extracts.

''The introduction of the vessels that swim under water has, in my opinion, entirely done away with the utility of the ships that swim on the top of the water''.

''Submarines and aeroplanes have entirely revolutionized naval warfare, no fleet can hide itself from the aeroplane eye, and the submarine can deliver a deadly attack even in broad daylight''.

''Submarines are difficult to destroy by reason of the difficulty of attacking an unseen enemy. A naval power which should send out its battleships to seek and destroy the submarine fleet of an enemy would run the risk of disaster. If submarines are noted in the neighborhood they should be avoided rather than sought. . . . .''

''What we require is an enormous fleet of submarines, airships, and aeroplanes, and a few fast cruisers''.

''If we are at war with a country situated within the radius of action of submarines, I believe that this country will be forced to hold her dreadnaughts in a safe harbor. We shall do the same . . . .''

''An island with many harbors and many vessels is a disadvantage if the enemy possesses submarines. . . . . .''

''I believe that the importance of submarines has not yet been fully recognized. I believe, also, that there is a like failure

to realize the extent to which their appearance has revolutionized naval warfare''.

''In my opinion, as the motor-vehicle has driven the horse from the road, so has the submarine driven the battleship from the sea''.

I close these citations and I conclude:

The submarine has already taken an important place in the composition of war fleets. This importance can only increase in the future. The war of 1914-15 marks an important date in the evolution of naval material.

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DISCUSSION

Naval Constructor Howard.

Naval Constructor H. S. Howard, U. S. N.,* wrote that the wisdom of two types of submarine did not seem absolutely apparent to him. Practically the same arguments applied in the past in the case of torpedo boats and destroyers. Now the former have disappeared. A large submarine, provided it does not become so large as to become unmanageable, can do all that a small submarine can do and more. At the present time the very large submarines, which this country and others are building, are very expensive—almost double the cost of a torpedo-boat destroyer—but costs will be reduced with experience. Mr. Howard agreed with the author that sea-going submarines of 23 knots on the surface and 15 knots submerged are the type desired, but said that no country is, so far as known, able to build submarines of those characteristics quite yet. Consequently, at the present time it seemed to him that submarines with a reliable surface speed of 18 or 20 knots, which can be obtained with installation of Diesel and steam engines with which there has been experience, are the best for all-round work. Submarines of this type, say 800 tons on the surface, 18 knots surface speed and 12 knots submerged, should be able to perform all the work of coast and harbor defence, and be real sea-going submarines. This type might not be so necessary for coast defence in a country with short coast lines, but for a country with extensive coasts, where it might be desirable to shift groups of submarines rapidly to a threatened position, it appeared as though they would be ideally suited.

It did not appear to Mr. Howard that the differences between submersibles and submarines, which the author enumerates, hold now-a-days

* Bureau of Construction and Repair, Navy Dept., Washington, D. C.

nor should in his opinion the types of vessels to which the author refers be called submersibles and submarines. He believed that the main difference between submersibles and submarines at first consisted actually in the difference in their ability to go to sea. The submersible possessed much higher reserve buoyancy and better form, so that the vessel was more seaworthy and habitable. The submarines, so-called of that day, were small, with little reserve buoyancy and speed. He admitted that the submersibles were double-hull vessels, but said that did not alter the case. These two types, he stated, have grown towards each other until the submarine, by increasing reserve buoyancy and habitability, has all the qualities of the submersibles; both have good reserve buoyancy and are habitable at sea. For these reasons it seemed to Mr. Howard that the names and the distinction of submarine and submersible should be dropped, and the two types referred to as double-hull and single-hull submarines. Referring to Chapter IV, Mr. Howard expressed the opinion that increase in displacement is not only necessary for increase in armament (which is not so important, as even the smallest submarines carry as heavy a weapon as the largest) but also to increase habitability and speed, i. e., to get the weapon to the point where it is wanted. Naval Constructor Howard.

Mr. M. A. Laubeuf, in closing, said that it is quite true that a large submarine can accomplish what a small one would, and even more. But one must take into account the expense, for the budgets of all countries cannot be expanded at will, and after the war many navy departments will have to become economical. So much the better for the United States if they can spend without counting. Mr. Laubeuf.

The difference between submarines and submersibles is decreasing more and more, as Mr. Howard states. What Mr. Laubeuf wished more especially to bring out is the fact that it is the submarine which is going towards the submersible, and not the contrary, and this is a cause of joy to him, being the inventor of the submersible type.

Paper No. 208

MODERN MARINE GUN ARMAMENT.

By

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(Authorized by Navy Department.)

About seven years have elapsed since the construction of the dreadnought was decided upon, and this period has witnessed the developments in the design and armament of capital ships, which may be taken to cover the progress of modern marine gun armament, as the revolutionary changes introduced at that time furnish a definite starting point. The plans of the dreadnought introduced a new governing principle into battleship armament, which has become known as the ''all big gun'', or ''single caliber'' armament, in contradistinction to the previous type of armament, which consisted of at first three calibers, and then two, known as a ''mixed battery''.

Before proceeding with a discussion of the types and changes introduced in the primary armament, it may be well to state some of the reasons that led to adoption of this new underlying idea. The former policy of installing a mixed battery, with generally four guns of the heaviest type, and a large number of intermediate and secondary guns, was due to the erroneous belief that it was not advisable to increase the number of heavy guns due to the large increase in weight involved, and the slowness of fire from these guns. The intermediate guns, by their great volume of fire, were considered more effective against the personnel and upper works of the enemy, thus silencing his fire. It has been definitely established, as the result of target practice, that the larger the caliber the more accurate the shooting, and as the standard of gunnery effici-

ency is "rapidity of hitting", the all-big-gun, single-caliber ship has become recognized as affording the maximum of effectiveness. Additional reasons for this type are: the amount of armor that can be installed on a ship being limited, it is impossible to assign sufficient weight to adequately protect a long broadside of intermediate guns against the fire of heavy guns; also the presence of smaller guns reduces the rapidity of fire, hence the effectiveness of the larger guns, due to the interference in the fire-control arrangements. Modern vessels are now being successfully armored against the fire of small guns, and the personnel will be behind this armor; thus, the small gun will be useless except for defense against torpedo attack. The high state of development to which the torpedo has been brought has also led to an increase in the probable future battle ranges, again militating against the use of small guns in a main engagement. Thus, it is realized that with the increased rate of fire and accuracy of modern heavy guns at long ranges, the smaller guns, with their crews, would be destroyed before they came within their effective range.

The selection of the caliber and type of gun for the primary armament of a battleship is a problem which is open to great controversy. At the present moment, there exists a fairly strong current of opinion in favor of increase of caliber, as shown in the armament of the most recent ships of the principal naval powers. Nevertheless, some naval authorities indicate the probability and desirability of the return to more moderate calibers, or at least express some doubt as to the maximum efficiency to be obtained from the use of the greatest possible calibers. While, for a long time, the 12-inch gun has everywhere been considered as the maximum caliber for the primary armament of battleships, the movement in favor of increased calibers has today culminated in the actual manufacture of guns of caliber much greater than the one which hitherto has appeared to meet all requirements.

This general change of opinion, which has thus recently taken place relative to primary armament, is to be attributed in part:

(a) to the increase in battle ranges,

(b) to the improvement in armor,

(c) to the practice of filling armor-piercing projectiles with high explosives.

The increase in battle ranges and the improvement in armor, both necessitate an augmentation in the striking power of the battery. There are several ways of accomplishing the desired result:

(1) by an increase in the caliber of the gun,
(2) by an increase in the weight of the projectile,
(3) by changing the shape of the projectile to obtain better ballistic qualities,
(4) by increasing the initial velocity.

1. Bearing in mind that we are actually considering only the primary armament, that is to say, the 12-inch gun and those of larger caliber, we may say that it has been demonstrated by actual firing that a gun of larger caliber, having a moderate initial velocity, is able to fire a far greater number of accurate rounds than a gun of smaller caliber having a high velocity. Thus, since for the same velocity, at the same range, the penetration increases with the caliber; for a given penetration, the greater the caliber, the lower the velocity and the longer the life.

2. If the weight of the projectile is increased, while the initial velocity remains the same, a greater amount of energy is obtained from the gun, and the penetration is superior at all ranges; but it must be borne in mind that the increase of energy is obtained by an increase in the weight of the charge, and an increase in the maximum pressure, which means an increase in the erosion of the gun equivalent to a diminution in accuracy and in the life of the gun. An increase of weight with a lower muzzle velocity may give better penetration at long ranges, but the loss in danger space must also be considered. An increase in the angle of fall also increases the cross breaking stresses of the projectile on impact.

3. By changing the shape of the projectile, a very material increase in range with a corresponding increase in flatness of trajectory in danger space, and finally in striking velocity and penetration are obtained, especially at long range. By changing the radius of the ogival head from 2½ to 7 calibers, the

striking velocity has been increased at the battle range of 12,000 yards by fully 30 per cent. The value of this change can not be emphasized too strongly, for it is a gain in the true sense of the word, since it increases the value of ship's batteries by 30 per cent., without any cost whatever; the charge, the velocity and the pressure being the same for a long-pointed projectile as for a blunt-pointed one, the gain being due entirely to the reduction in the resistance of the air to the projectile in flight.

4. By increasing the initial velocity, the striking energy of the battery can be increased; but in this case, as well as that of the increase in the weight of the projectile, the gain can not be obtained without increasing the charge, the maximum pressure, and the erosion; consequently not without shortening the life of the gun.

The practice of filling armor-piercing projectiles with high explosive is now almost universal. The general tendency, at the present time, is to require projectiles not only to perforate the heaviest armor now existing or foreseen, but also to carry a large charge of high explosive. It appears that at the battle ranges now contemplated the 12-inch projectile is not equal to the double demand; while it might perforate the armor, its charge of explosive is too small to produce the destructive result desired. If a large projectile has a perforating power greater than the heaviest armor, it is clear that the capacity of the shell cavity can be increased more than proportionately to the increase in caliber. Thus, the larger the caliber, the greater the shell cavity, the heavier the bursting charge, and the greater the efficiency of the projectile.

It has been proved by actual firing, as before stated, that the larger the caliber the more accurate the shooting; consequently, from the viewpoint of accuracy, penetration and effectiveness, the caliber of the gun for the primary armament should be as large as possible. Now the larger the caliber the heavier the armament, and the greater the space required for its installation on board ship, where these two factors, weight, and space, are always limited; consequently, as in most engineering questions, a compromise must be made to determine the "smallest big gun" that will fire a projectile, that not only

penetrates, at battle ranges, the heaviest armor afloat, but also carries a sufficient quantity of high explosive to ensure the desired effect behind the armor; all this with a reasonable margin of assurance and no more.

The caliber of the primary armament varies at present from 12 inches to 15 inches, and it appears as if the 15-inch, or even the 14-inch, will be the limit of caliber for this armament. Considering the 15-inch gun, for instance, this gun will penetrate the thickest armor belt of any ship contemplated, and is carried as high as a turret gun can be carried (maximum about 30 feet). To mount primary guns higher than this above the water line is to unduly expose them as targets, and injuriously affect the stability of the vessel. Even at this height, a poor horizon is obtained at over 12,000 yards, and due to the angle of fall of the projectile, direct hits would be exceedingly difficult to obtain. If the gun could be carried at a greater height, then the advantages of a larger caliber might be apparent, but otherwise it seems as if the logical limit in the size of the gun has been reached at 15 inches; and in all probability a 14-inch gun of higher velocity is preferable, due to the gain in weight involved in the ammunition and the more numerous battery that may be carried.

It is believed that one reason, leading to the adoption of the 15-inch gun by the British Admiralty, was the desire not to mount more than two guns in a turret. Thus, the number of turrets being fixed, to equal the muzzle energy of ten 14-inch guns on the same displacement, they were forced to adopt a larger caliber.

The most advantageous composition of battery, as regards the caliber, for the primary armament having been determined, it remains to decide upon the arrangement of battery, in order to obtain the greatest arc of fire, or maximum fire efficiency from each gun. As the ahead-and-astern fire is necessarily limited, and must always be less than the broadside fire, it follows that main engagements will tend to use broadside fire, in order to have the maximum number of guns in action; and as a gun that fires on either broadside is equal to two guns that fire on one side only, the endeavor is to place all, or as many guns as possible, on the center line, due regard being paid to

obtaining the greatest height above the water line consistent with maintaining the proper stability of the vessel. Great care is also necessary to avoid "interference" between guns, due to blast effects, etc. Superposed turrets, which increase the number of guns, are objectionable, as they are too cramped to furnish proper ammunition supply, and add materially to the height of the enemy's target. It was the recognition of the above principles by American designers, in the plans for the "Michigan" and "Delaware" classes of vessels, that first led the way to the now accepted design for vessels of the dreadnought and super-dreadnought classes.

The most conspicuous result of the adoption of the all-big-gun principle has been the intensified competition between naval powers for the possession of the largest and most powerful units; the result being an expansion of dimensions aimed at increasing the actual, or proportionate power, of the broadside by adding to the number of guns available on the beam. The first vessels built on the new principles for Great Britain, Germany, Japan and the United States, all had eight guns bearing on the broadside, but with differences in the aggregate power required to produce the broadside. As stated before, the "Michigan" class obtained it with a total armament of eight big guns, having four twin turrets on the center line. The Dreadnought needed 10 guns, having only three turrets on the center line, and two abreast on the beam. The Germans and Japanese had six twin turrets to produce an 8-gun broadside, two turrets only being on the center line, the other four being placed in pairs abreast. The "beam fire efficiency" of the various types—the relation of broadside to total armament—was therefore 100 per cent. for the United States, 80 per cent. for the British, and 66.6 per cent. for the German and Japanese. The United States' design undoubtedly was, and is, the most efficient, and has been consistently followed ever since by its Navy Department. All other powers have come to this center-line arrangement for their capital ships, the difference being merely in the number and caliber of guns adopted for the primary armament.

The American practice is that the controlling factor in battery arrangement is the number of turrets and not the num-

ber of guns; and it is believed that the four 3-gun turret arrangement of the "Pennsylvania" presents the best solution of the problem.

To sum up, the general conditions governing the primary armament of the modern capital ship are as follows:

(1) the greatest weight that can be allowed to the armament,
(2) the number of guns required,
(3) their disposition within each turret (twin, triple, or quadruple),
(4) the disposition of the turrets, superposed, etc., affecting the weight of the armor carried,
(5) the weight of the projectile and the number of rounds of ammunition to be carried by the vessel.

It is evident that for similar types of guns and turrets, the larger the caliber of the gun, the larger will be the turret and the greater the ammunition weights; and although modern design has done something to reduce the ratio, it is still very large.

Another important influence on the weight of the total gun mounting is the extent to which the alternative systems of power and hand working are employed. Furthermore, the question of perfect balance means increased weight over a design where these considerations are not weighed too carefully.

A prime necessity in ordnance design is to ensure that the gun pointer can manipulate with ease the elevating and training gear. The transporting machinery in the shell room and magazine must be capable of rapid movements, and the methods for bringing ammunition from the hoists into the guns must be simple and expeditious, and necessitate only the minimum of fatigue to the crew, while maintaining a continuous supply over a protracted period. These desiderata in design involve the question of the choice between hydraulic and electric prime movers. Reliability is the first consideration. It is essential to obviate any chance of derangement by shock of direct impact, and as far as possible, from the shattering effect of high explosive shell bursting in the vicinity of gun machinery.

There is a marked tendency, at the present time, favoring the adoption of electric machinery; the principal exception being the British Admiralty, who have stuck to the hydraulic gear, that they have highly perfected as the result of years of use. Inasmuch as certain gear in the turret must be run by electricity, and that this source of supply must be present, the electric installation throughout is considered a better solution of the problem.

The device, which is now coming into almost universal use for gun-elevating and training, is the Williams-Janney transmitter, which has immense potentialities not only for such systems, but for the many cases where precision of control is desired in combination with great variation in the rate of revolution. In this transmitter a body of fluid is employed to transmit the power from the motor to the shaft or mechanism to be driven. With this apparatus the motor runs at a constant speed, and in the same direction—desiderata for efficiency in all electric motors,—and no reversing of the motor is required to obtain a change in the direction to which power is transmitted. The Williams-Janney transmitter, or "Universal Speed Gear", by the simple movement of a lever, reverses the direction almost instantly, notwithstanding very high speed of rotation either on the part of the motor, on the one hand, or of the motion shaft on the other.

There are two general systems in use in turret loading arrangements known as the "variable position" loading arrangement, and the "fixed position" arrangement. In the variable position scheme, the ammunition hoists, at the upward end of the travel into the turret, are guided on curved rails, concentric at the upper ends with the gun trunnions. Thus, at the end of travel, the projectile comes into direct line with the chamber of the gun, irrespective of the angle of elevation. The rammer is thus easily brought into contact with the base of the projectile, while the point is immediately opposite to the center of the breech opening. The rammer now usually adopted is of the flexible chain type. It is in the form of a series of links, which can be coiled up, thus occupying very little space in the turret chamber. The links of the chain are so formed that when extended by means of a motor, the abut-

ments of the links keep the chain rigid, and prevent any sag beyond the predetermined amount. On running the rammer back from the gun, after the charge has been driven home, the links are automatically turned and form a flexible chain for convenience in stowing. Interlocking gear is provided, so that the rammers cannot be operated unless the hoist car is in the correct position behind the gun for ramming the projectile home. Similarly, the car can not be lowered until the rammer is housed. By these means, even while being loaded, the gun can be elevated at the will of the gun pointer. This is, of course, a result of mounting the loading gear on the gun slide, which moves with the gun in a vertical plane. The advantages of this scheme, with its added complications, are considered of doubtful value, and in the American Navy, the guns are loaded from a fixed position, the rammer being mounted in the rear of the turret, and the gun brought in line after each discharge. As there is no real advantage in keeping the gun on the target during the loading interval, and as the gun can be generally brought on the target in the time required to close the breech and prime the gun, the simpler plan of a fixed position is considered superior.

The recent results obtained by the "Director" method of firing have shown the advisability of having turret guns cross-connected, so that they can be elevated together and controlled by one firing pointer, and all turret arrangements now provide means for accomplishing this result. A still further step in the same direction consists in mounting two or more turret guns in the same slide, so that they are always elevated together, and this introduces the further advantage of decreasing the distance from center to center of guns, thereby reducing the diameter of the turret, and greatly reducing the weight of the turret installation. It is not believed that more than three heavy guns can be so mounted, and any greater number would probably have to be handled by pairs of guns in the same slide. The great advantages of placing the greatest number of guns under the direct control of the fewest pointers are considered of much value, and the only drawback to the scheme is the dispersion of fire that may be introduced due to the varying droop of the guns, and the muzzle-blast interferences of the

guns so closely mounted together. These are points that can only be determined by actual service firing afloat, and the results will be of vital interest to ordnance design. There is still a strong prejudice in favor of not mounting more than two guns in a turret, on the theory of not placing too many eggs in one basket; but the advances in turret construction and armor protection, coupled with the increasing importance of minimizing weight, and the difficulty of finding more than four good turret locations will undoubtedly overbalance these considerations, if the disadvantages cited above do not prove of serious moment.

The detailed arrangements of ammunition supply differ on nearly every class of vessel, but certain general principles are now commonly adopted, such as the use of what is known as "two-stage" hoist, the powder being brought up from the magazine to a working chamber below the guns in one hoist, and from there to the guns in a second hoist. Some schemes send powder and shell up in the same hoist; others use separate shell and powder hoists, and the latter scheme is considered more reliable and efficient, as a temporary failure of any one hoist could be made good from those not affected.

The breech mechanisms of all large guns are generally operated by power, due to the heavy-weight plug involved, and in order to ensure smoothness and regularity of operation. In the American Navy, however, a balanced mechanism has been adopted, that can easily be operated by hand or air power, this air being used only for closing the breech mechanism, the opening being always by hand, thus tending to rapidity and simplicity.

One of the most serious questions, perhaps the most serious, which imposes itself upon the mind regarding a vessel's armament, is that of the life of large-caliber guns; this life has become exceedingly short in consequence of the use of smokeless powder and high-service pressures. Thus the problem of reducing and combatting the gun erosion is one of the most interesting, and at the same time, one of the most difficult that ordnance experts have been called upon to solve. Owing to the great increase in the cost and power of modern ordnance, and the consequent increased importance of gun erosion, it has

been the subject of a large amount of study and experimentation during the past few years. The net result of these experiments and researches tends to show that erosion is of two kinds—that caused by the escape of gas, and that due to the rush of gas behind the projectile. As both kinds manifest themselves by a fairly uniform wear of the bore, it is not possible to state their relative value.

The necessary conditions for producing erosion are the heating of a thin film of metal, together with the rush of the powder products over this heated surface. In a given time, greatest erosion will occur in the gun where these two factors have their greatest erosive relation. Erosion occurs with high temperatures of metal and relatively low velocity, and likewise with high velocity of gas and low temperature of metal, as shown by the muzzle erosion; but in all cases to produce any appreciable erosion, a thin film of the metal of the bore must be heated, and the products of combustion must pass over this film at considerable velocity. Friction is necessary to produce erosion, as there is no erosion in closed bombs in which pressure and temperature are the same as in guns. There must, as stated, be motion of the products of combustion to cut or wash away the weakened film of metal. The friction is increased by the rotating band of the projectile, which friction is very great. The time element is also of great importance, for the quantity of metal washed away increases with the time of action. The greatest erosion occurs at the origin of the rifling, where the relation between the time, temperature of the bore and the velocity of the gas (aided by the friction of engraving the band) seems to be at a maximum for producing erosion; also the time taken by the projectile to travel one caliber down the bore is roughly 50 per cent. of the time of total travel. Since the weight of charge increases as the cube of the caliber, and the surface for absorbing heat only as the square of the caliber, also the time of action of the gas being greater (being proportional to the caliber), it is found (other things being equal) that erosion is greatest in the larger caliber guns. The great disadvantage of erosion in guns is that it washes away the rifling, and injures the bore at the origin of rifling. There results a reduction in pressure and velocity, due to increased powder chamber, and ultimately the rifling may be so nearly

obliterated, that the projectiles do not get the proper rotation and give inaccurate flight.

The life of a gun is the number of service rounds which can be fired from it before it loses its energy sufficiently to be condemned. Although minor modifications in shape of powder chamber, type of rifling, and kind of band on the projectile have made slight improvements, it is clearly demonstrated that erosion is a function of the melting point of the metal of the gun bore, and as long as the combustion of the powder produces a high temperature and pressure, erosion will exist. Therefore, the only resource is to devise a system of rapidly relining guns to replace those worn out in service. The progress along these lines has been marked; and by the use of conically shaped liners, the necessity of boring out the gun bore is obviated, and the time necessary to reline a gun greatly reduced. The liner is made with the same taper from muzzle to breech, the direct continuity of the taper being interrupted by several steps or shoulders, located so as to minimize the creeping of the liner, and distribute possible flow of the metal itself. The liner may be either forced in the gun with hydraulic pressure, both gun and liner being cold, or a nominal shrinkage may be used, the gun being heated to 150° to 200° F., and the liner shrunk on. After finishing off the breech end of the liner, the breech bushing is screwed into place. This bushing locks the liner to prevent any rearward movement. When it is desired to renew the conical liner, the gun is put breech down in a furnace, and heated until it has attained a temperature of about 250° to 300° F. The heat within the bore is then withdrawn, but continued on the outside. A spray of cold water is driven through the bore from the muzzle end, and the sudden cooling of the liner causes it to contract and free itself; or it is hammered out by a falling weight. The bore of the gun is then examined, smoothed up if necessary, and the new liner inserted. The advantages of the conical liner are:

(1) facility of removal of worn liner,
(2) reduction in high temperature necessary to remove a straight liner,
(3) lessens the risk of the liner sticking or galling in assembling,
(4) great reduction in time necessary to reline.

The possibility of inserting finished liners in the relined guns is being investigated, and if a feasible scheme is found, the time of relining can be reduced by more than half. Any progress in this direction is thus of the most vital importance, as it means a direct military gain in the reduction of time a gun is out of commission for relining. The above has a great influence on the number of reserve guns necessary, as by having a rapid method of relining available, a stock of finished liners may be substituted for some of the reserve guns, and the cost of keeping the fleet's main battery ready for action at all times greatly relieved. To prevent the liner from rotating, due to pressure on the lands of the rifling, the outside of the liner is "combed" or cut with longitudinal grooves.

One of the most important questions faced by the ordnance designer of modern high-powered guns is the question of droop, or the amount the muzzle of the gun sags due to its own weight. It has been found that nearly all guns have a muzzle droop that can be measured. This is naturally greatest in the longer and heavier guns, but there is, in addition to the downward droop, a deflection to one side in almost every gun. The droop is partly elastic, for when a gun is placed upside down, it also droops a certain amount. In almost all cases, however, the greatest droop occurs when the gun is in the normal position. This droop varies somewhat, from time to time, as the stresses of the gun vary by firing, also due to the temperature of the two sides of the gun. As the gun is fired, the forces acting in the bore tend to straighten it, and the various forces set up vibrations, which cause the muzzle to describe a curved figure to the right and above its position in the state of rest (for right-handed twist). The results of firing tests have proved that practically all of this muzzle movement takes place after the projectile has left the bore of the gun, and thus does not seriously affect its flight. There is no doubt that flexibility is undesirable, and every effort is made to reduce it as much as practicable in gun design, as it affects the question of relining guns seriously. The droop with the wire-wound gun is roughly twice that of the built-up gun, due to loss of longitudinal or girder strength. From data at hand, it appears that the only firing error caused by droop is due to the variation in droop

among various guns on the same vessel. Droop appears to vary with life of the gun, depending on the part of vibration reached as the projectile leaves the bore, but repeated firings cause a gradually increasing droop. The effect of droop is to cause the projectile to leave a curved bore, taking the direction of the final tangent, and this has been verified by firing tests. If the top of the gun is heated more than the under side, due to exposure to sunlight, the result is to make the gun droop downward away from the sun, but as the results of some very careful experiments, it appears that, considering other unavoidable causes for variation, that which is due to the change in temperature may usually be neglected, especially aboard ship where, due to the movement of the vessel, the apparent wind created will cool the gun, and the changes in course steered will reduce the effect of sunlight.

The composition and arrangement of the primary battery having been decided upon, the secondary battery for defense against torpedo attack is necessarily fixed by the locations left available. From the axiom that the larger the caliber the greater the hitting power, these guns should be of the largest caliber consistent with great rapidity of fire, and in order to ensure the most effective control, should all be of the same caliber. These guns are arranged, after the plans for the main battery have been determined, in the best positions possible to give the greatest arc of fire to each gun, and to cover all points of approach. The above arrangements have led to the new type of vessels being armed with two calibers, consisting of the "smallest big gun", and the "largest little gun", that will effectively answer the tactical requirements imposed.

The trend of ideas with regard to secondary or anti-torpedo armaments has been to increase them as regards either caliber or number, or both. England began by giving the Dreadnought 24 three-inch guns. All subsequent vessels down to the "King George" class have had 4-inch guns, the number being generally sixteen. Later vessels have 6-inch guns. This tendency has been general, the United States advancing from 3-inch to 5-inch guns, which caliber has been consistently adhered to, their number being gradually increased from 14 to 22, the larger number being mounted on the four turret vessels

now under construction. Thus opinion is fairly unanimous in favor of a 5-inch or a 6-inch gun, but as the latest trend in design seems to be more influenced by a desire to "go one better", rather than to produce a vessel in agreement with the proper tactical requirements, it is probable that before long we will see the anti-torpedo battery developed into a secondary battery proper.

As stated above, the general consensus of opinion is in favor of a 5-inch or a 6-inch gun for torpedo defense armament of battleships, and that these guns should be mounted as high as they can be properly located, to produce an all-round defense and not interfere with the main battery.

The threat of a day attack by destroyers has led to the proposal to mount the torpedo-defense guns in small turrets, in order to give better protection to their crews during an engagement, and to protect them from the blast effect of the main battery; but due to the difficulties attendant upon securing suitable locations for the small turrets, and the fact that in order to have any real protection, the armor would have to be of the heaviest type, this scheme has not been adopted, or even seriously considered by any of the principal powers.

The best gun for the purpose is that having the flattest trajectory, within the limit of night torpedo attack, combined with the greatest rapidity of fire and least smoke and flame interference. The use of rapid-fire guns, using metallic cartridge cases, has been abandoned in favor of guns using powder bags only, as the rapidity of fire is greater, and there is no accumulation of empty cases in rear of the guns to interfere with effective loading. The requirements of a high velocity, flat trajectory, torpedo-defense gun have brought to the front the question of erosion in these guns, and reserve guns in larger numbers than heretofore will have to be maintained to compensate for the decreased life involved.

The rapidity of fire desired from modern secondary gun armaments requires increased speed of manipulation, and to be of value, also accurate and effective sighting arrangements. In order to enable the gun pointer to perform his task to the greatest advantage, his position should be as comfortable and natural as possible, in order to reduce his exertions as much

as practicable. This has been accomplished by locating the eyepiece of the sighting telescopes as near the center of the trunnions of the guns as is permissible; and to increase the accuracy of control, double-drive elevating and training wheels were introduced. To cover the different conditions arising, due to varying roll of the ship, and apparent speed of the target, two speeds of elevation and train are provided, the shift being by means of a lever conveniently located. On some vessels. power elevating and training gear has recently been adopted for these mounts.

For use on destroyers, the 4-inch gun is about to supersede the 3-inch, and it is believed that no increase in caliber will be necessary for some time to come. These guns are the largest caliber of guns firing metallic cartridge cases, that will effectively answer the requirements of rapidity of fire and ease of elevation necessary for use on a destroyer, where the motion of the gun platform makes accurate pointing of extreme difficulty. It may further be doubted whether the change from the easily handled, extremely rapid-firing 3-inch guns on the destroyers to the slower and heavier 4-inch gun was a wise move. Due to the poor gun platform afforded by a destroyer, the effective range is extremely limited, and it is believed that a 3-inch gun will answer all purposes for attacking another destroyer, and that the increase of caliber has merely resulted in a curtailment of the number of guns carried and the ammunition allowance, or reduction in volume of fire. As destroyers will undoubtedly be continually used in scouting operations, the mounting of an effective gun armament should be most carefully considered.

The question of aerial defense is now occupying the minds of all the principal powers in regard to the armament of naval vessels, and up to date the opinion seems in favor of an automatic gun, firing a projectile filled with tracer fluid, so that the projectile may be followed in flight. These guns fire one-pounder or two-pounder shell, and will cover an area up to 7000 to 10,000 feet, or effectively prevent an aerial attack being pushed home. Up to date, vessels are being armed with from two to four of these guns, mounted so as to have all around fire. The only other type of aerial gun used is a 3-inch

rapid-fire gun, firing shrapnel, but the difficulties attendant upon determining the range of an aerial craft, and unreliability of fuse action, are believed to be so great, that this method is considered as much less effective than the use of an efficient automatic gun of smaller caliber firing solid projectiles.

Another point which has recently arisen regarding armament is that of submarine vessels, and the development of a satisfactory design is attended with more difficulties than for any other class of vessels, due to the question of housing and protecting the gun during submerged runs. The mounting must be of the most compact type permissible, in order that the submerged speed of the vessel may be reduced as little as possible, and also the time required to bring the gun into action on rising to the surface must be as small as possible. It is understood that the calibers as high as six inches are in contemplation for use on submarines, and the number mounted has already been increased from one to two; but this number will not be increased for some time, due to the difficulty of securing additional satisfactory locations. The caliber in favor at present seems to be the 3-inch gun of fairly low velocity, in order that the gun may be of short length. There are two general types of mounting in use—the water-tight, and the non-water-tight; the latter requiring the use of special material to avoid corrosion. It is believed that the water-tight design, with vertical housing, is the most efficient type yet developed, as it involves the least resistance with vessel submerged.

Paper No. 209

THE GENERAL PROBLEM OF NAVAL WARFARE.

By

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It is sometimes lightly assumed that war is a matter in which only the Army and the Navy are greatly concerned. This superficial view is held more particularly among the people of countries like the United States, located far distant from all strong military powers and having a weakly centralized form of government; and in such nations this fallacious opinion constitutes one of the greatest difficulties in connection with the general problem of naval warfare which naval officers are called upon to combat.

War is no longer the plaything of kings and nobles, but nowadays is in the broadest sense a national act, permitted by public opinion in enlightened countries only when the national honor is imperiled or vital interests jeopardized, and under these circumstances usually forced upon the nation by the people regardless of the wishes of those in high authority.

The bearing of national honor upon war requires no comment here; but the relation of vital interests to the "great arbiter" will profitably bear closer examination. Because of innate conditions, such as geographical position, topographic and hydrographic features, material resources, the state of industrial development, density and growth of population, racial characteristics, etc., every nation has certain interests which exist inherently, and quite independently of human desire or design.

For example, it is obviously to the interest of the United States to control the isthmian waterway at Panama. Her two

widely separated coasts with unequally distributed population, industries, and resources, demand it. Equally is it essential to the welfare of the United States of Colombia, which possesses seacoasts upon both oceans, to control this isthmus. The interest of Germany in the control of the Dardanelles and the Bosporus is not so obvious, yet it is vital to her. The German population, already too large to be easily supported by the area and resources of the country, is rapidly increasing, and consequently some outlet is necessary. On account of her geographical position in the heart of Europe, surrounded by populous nations of great military strength, some of which, notably Russia, are also growing rapidly in population, emigration which involves a change of citizenship is the equivalent of eventual national ruin. Territorial expansion overseas is debarred because all suitable areas are already taken up by other strong nations, and the geographical position of England, the mistress of the seas, renders such an outlet too precarious for stable development. While it might be possible for Germany to build up to England's fleet and to dispute with her the control of the oceans, such an effort would require an expenditure so great as to imperil the more vital security of the empire on land. The only safe outlet compatible with national aspirations and a long continuance of national existence, is that offered by the rich, thinly populated areas of Asia Minor, where German settlers and their descendents would probably remain loyal to the Fatherland indefinitely. An expansion in that direction can be made overland, secure against the threat from British sea power so long as the narrow waterways connecting the Mediterranean and the Black Seas remain in the possession of Germany or her allies.

It is practically impossible for human minds or hands to measurably alter the inherent conditions which prescribe the vital interests of the various world states. These conditions, and the resulting interests, remain substantially fixed for very long periods of time, and therefore the national policies which emanate therefrom have a great degree of permanence. For hundreds of years the control of the Bosporus and of the Dardanelles, the natural outlets of the vast territories inland from the Black Sea, has been a matter of vital consequence to the people

inhabiting Russia. It was true long before farseeing statesmen recognized it to be a fact and adopted it as a Russian national policy, because the geography of that region creates the inherent conditions, and inevitably out of such antecedents the policy came into being.

The control of the Black Sea outlets also happens to be vital to the welfare of Austria, because her main commercial artery, the Danube, empties into the Black Sea; and, as has been indicated above, vital to Germany. Obviously is it also essential to Turkey that she control the important straits under discussion. Consequently there is a clear cut clash of inherent interests between Russia on the one hand, and Germany and her allies, Austria and Turkey, on the other. It is not surprising, therefore, that equally conflicting national policies have been derived from these interests; nor that the constant opposing pressures of them have led to the present war.

And so it must always continue that wars will grow out of conflicting interests; at least until races become more nearly amalgamated in both blood and understanding, and until human nature comes to be less selfish; both of which processes are so slow as to be all but inappreciable. Before such changes can bring lasting peace, many wars will start and end, and many peace movements prosper and wane.

In the meantime statesmen and governments will continue, as heretofore, to discharge well, or to neglect, the responsibilities to the people of their country which are unavoidably associated with public office. Such responsibilities inevitably include both wisdom and foresight in formulating and adhering to those national policies which are the logical outcome of the vital interests of the people inhabiting the country, as determined by the inherent geographical, racial, economic, and other conditions.

WAR AND DIPLOMACY.

The advancement and safeguarding of national interests is primarily a matter of diplomacy. During the normal long periods of peace, government officials who are charged with the conduct of a nation's external affairs should endeavor to "promote the general welfare" by means of treaties, and other

forms of international agreements. In such negotiations preparedness for war and potential force are important factors; without them diplomatic effort is frequently rendered impotent to a great degree. But even when the influence of force is eliminated, the character of the diplomatic endeavor remains unchanged, and continues to be essentially a competitive struggle for national advantage. Obviously diplomacy is primarily an instrument of policy.

When its peaceful efforts fail, diplomacy, in trying to support the national policies, must sometimes resort to war. But in so doing, it does not then go out of existence; war is merely one phase of diplomacy, the mission of which under all circumstances, either of peace or of war, is to uphold the national policies; and the declaration of war is itself an act of diplomacy. "War is merely a continuation of the Diplomatic Battles which are in progress at all times during peace".

THE STATESMAN AND THE WARRIOR.

As stated in the preamble of the American Constitution, among other purposes the government of the United States is established "to provide for the common defense" and "to promote the general welfare". The latter object is inevitably bound up in the formulation and maintenance of wise national policies which have their roots in the interests of the nation.

A clash of interests between two nations does not invariably lead to war; but if the policies resulting from such interests are sufficiently vital and positively conflicting, the diplomatic struggle must be supported by actual or threatened force unless one of the nations is content to surrender its "place in the sun" and perhaps to endure industrial death with its attendant poverty and suffering. The people of most self-respecting world powers are not content to sink to such depths without vigorous efforts to preserve the national dignity and existence, and consequently it becomes the duty of governments to "provide for the national defense".

Preservation of the national existence is obviously a national affair; and not merely one which alone concerns the military and naval forces. All branches of the government, as

well as the people of every class and condition are affected. Consequently the problem of national defense is at its base one of stupendous coöperation of all forces in the state—naval, military, diplomatic, financial, industrial, political, and moral.

It is a recognition of this comprehensive nature of national war and the consequent imperative necessity for national coördination which in recent years has led the profoundest military and naval thinkers of all great nations to advocate the creation of a "Council of National Defense", composed of representative officials from all branches of the government. For example it has been proposed that the "Council" for the United States comprise such officials as the President, the Secretaries of State, War, Treasury, and Navy, the Chairman of the Committees of Ways and Means, Naval Affairs, and Military Affairs of both Houses of Congress; and certain appropriate Officials of the Army and the Navy. Most of the other great powers have already created a similar "Council", the function of which is, in general, to ensure that the efforts of the nation as a whole are coördinated in such work of preparation for war as may appear necessary to adequately provide for national defense, national welfare, and the preservation of national honor.

It should not escape notice that the only role of the Council is one of peace preparation; specifically in the formulation of plans for governmental coöperation before and during war. Once hostilities are begun, it has no part in the direction of military activities, because experience has conclusively demonstrated that the conduct of war had best be left to those trained in that specialty.

That some kind of Council of this sort is an important and essential link in the chain of preparations necessary to safeguard the nation has been amply proven in the present great crisis in Europe. In those countries having such a coördinating body, the efforts of the several branches of the government were unified at the outbreak of the war in a manner previously unknown and beyond expectations.

Without such coördinated preparation, the Army and the Navy are in a position at the outbreak of war comparable to that in which the field force of an engineering corporation would find itself should it undertake construction work without

the assistance of the coördinated efforts of the planning, financial, executive, and other managerial departments.

The experience of the United States during the civil war, as well as that of every other nation which has engaged in war, has amply demonstrated the wisdom of the above described general relation between the civil branches of the government and the armed forces. Yet it seems difficult, more especially in a Republic, for the people and the civil branches of the government to profit by such experiences when the passage of time has eradicated vivid recollections. Consequently the failure of the country at large and of the government as a whole to comprehend and to carry out their duties in respect to the national defense is likely to constitute one of the gravest of the problems confronting the Army and the Navy. The situation is rendered all the more difficult for them, when, in their efforts to remedy it they may be charged with selfish motives.

From the point of view of naval and military officers, and in the opinion of the greatest authorities on war, it is fundamental that war should not be undertaken except in furtherance of specific policies clearly defined in advance; that adequate preparation for the maintenance of those policies should be made before war comes; that the responsible naval and military officials be thoroughly acquainted with the policies at issue; and that in the prosecution of the hostile campaign the strategy adopted by the armed forces shall conform rigidly to such policies, as interpreted for them by the Diplomatic department of the government.

Only by adhering to these principles may a nation engage in war with proper assurance of success in upholding the national policies and of safeguarding the vital interests from which they flow. Nearly all strong nations prepare for and conduct war in accordance with such principles, and it is obvious that no country should practice less scientific methods unless it is ready to abandon without fighting any of its vital interests for which rivals are willing to fight. In the present state of the world's development, the principle of the survival of the strongest and fittest applies to nations in much the same way as it formerly applied to wild beasts and to men. However greatly peace may be desired, it must be recognized that

among the nations all are competitors, some of whom may not love peace or may prefer war to material ruin, and that in the present day and generation the price of "national welfare" and national existence is adequate preparation for war, and a willingness to fight should genuine need arise.

STRATEGY.

According to Clausewitz, strategy is the "Art of using battles in war". In the first instance the time and place of battles should be planned with a view to furthering the specific policies which are in dispute. As Spencer Wilkinson, the eminent English writer expresses it "The fundamental condition of success in war is harmony between policy and strategy".

It follows that an important part of the General Problem of Naval Warfare is that relating to the performance by the Diplomatic and other civil branches of the Government, of their true functions as heretofore indicated with respect to the external interests of the nation.

Upon their doing so depends, in great measure, the ability of the Naval Officer to fulfil his own duty to the country which he has sworn to defend. His possible handicaps resulting from inadequate material provision by the civil appropriators are obvious. Equally serious and important, though less generally understood, are those which have their origin in deficient interior governmental coördination, and in inadequate definition of national policies.

Strategy cannot take definite form before the ends to be attained by it are clearly formulated by statesmen and made known to the Naval and Military commanders. Preferably this preliminary should be done during peace, so that the broader aspects of the case may be properly studied and ample time given to the preparation of the war plans—a process which involves long and painstaking effort by many men.

Incidentally such a method favors the practice of what is known as "Peace Strategy"; which consists of not only a peace distribution of forces which conforms to the initial requirements of the plan, but also diplomatic negotiations calculated to further and strengthen the particular policies decided upon.

To engage in hostilities without knowing and thoroughly grasping the ends to be attained invariably results in weak, vacillating, and unsuccessful strategy, and under such circumstances, even though success may be gained in the tactical combats, the war as a whole is likely to be fruitless of benefit to the national vital interests; and consequently a needless waste of money, effort, and human life. Such a result is sometimes brought about through an overweening love of peace and a consequent neglect to determine upon national policies in advance, and to properly prepare and plan for such wars as are probably inevitable if the policies are to endure.

After being made cognizant of the policies to be upheld, the plan making body, which in the Army and Navy of nearly all great powers is a General Staff, studies the situation exhaustively. Such deliberations obviously should include careful consideration of the policies and inherent interests of other nations likely to dispute the issue, and deductions should be drawn indicating the most probable enemy or enemies. Then should follow reasoned conclusions as to the general theatre of the war.

For example, should plans be under consideration for upholding the Monroe Doctrine, it will soon become apparent that none except a European nation is likely to dispute it. After having determined which one of them would most probably quarrel with us on this score, our plan makers would probably decide upon a strategic defensive for the initial stages of the campaign, and plan to establish control, or "command" of the eastern Caribbean Sea.

In reaching such a decision several aspects of strategy would be involved, and the conclusion would doubtless be supported by some such reasons as the following:

1. If our fleet is placed in the eastern Caribbean, it is then in the best position to support the policy which is disputed; because the fleet of any European Power having South America, the western Caribbean Islands, or Central America, as an objective could not safely proceed to those places in force, so long as our intact fleet occupied a position flanking its communications.

2. The United States fleet could safely be sent at least as

far from the home coasts as the Caribbean Sea, without running any risk of a serious invasion of its own country by the enemy, because such an attack could not be attempted until after our fleet had been destroyed or decisively defeated; and even minor landings or bombardments are not likely to be undertaken by the hostile fleet in the face of shore coast defenses and the submarines which would probably be left on guard at home.

3. In the nature of the case the United States fleet would be the weaker, because no inferior naval power would dispute such an exclusively American policy.

4. Upon arrival on this side of the Atlantic, after such a long journey, the hostile fleet would imperatively require the immediate use of an adequate base in which to refuel and repair its ships, and to rest the personnel of the destroyers and submarines.

5. Such a base, suitable from both a hydrographic and strategic standpoint, is only to be found in the Caribbean Sea.

6. The advantages to be gained by harrassing, and if possible attacking the European fleet before it can arrive at its much needed base, and make itself secure therein, preliminary to a subsequent exit in a refreshed, rejuvenated, and generally much stronger condition, are not to be neglected if victory against the superior fleet is ever to be gained.

As has been indicated the question of fleet position is a matter in which Strategy has a deep concern, not only in its relation to policy but also to lines of communication with home sources of supply. The integrity of lines of supply is not so pressing a matter afloat as it is ashore, because armies cannot carry with them, as fleets do, several weeks' supply of the necessaries of existence. Nevertheless a fleet which permits the enemy to interrupt its communications must force the latter to accept action and come out decisively victorious, if surrender due to material starvation is to be avoided.

The question of bases is also of great strategical importance. Unlike an army, which can advance beyond its base and remain away from it almost indefinitely by merely extending the connecting line of transportation, the distance which a fleet can steam away from its base is inflexibly fixed by the steaming radius of the ships, and a return to base for refueling and re-

plenishing is always necessary after a comparatively short length of time. Limiting as it does the operating area of the fleet, the position of the base is a vital question in its selection. Of almost equal importance is the matter of the facilities which the port affords, chiefly in the way of size of anchorage ground, depth of water, smoothness of water, protection against submarines, and defensibility from land attack and sea bombardment.

The fleet is fortunate which, at the outbreak of hostilities, finds itself in possession of a base properly situated in the theatre of hostilities, and well fortified and provided. Usually the question of expense alone is sufficient to prevent the proper preparation during peace of such bases in all the probable areas of operation. Consequently if its mobility is not to be fatally restricted during war, a fleet must be prepared to itself seize and establish bases at the times and places which strategy and other circumstances dictate. Preparation in this respect usually consists of a number of transports carrying an outfit of harbor defense mines, landing guns of sufficient size to protect the mine fields from sweeping operations, and troops in such numbers as are considered necessary to prevent the enemy from capturing the base by land operations. To be suitable for this kind of service the troops employed should be very mobile and specially trained and habituated to the work. A fleet so prepared is free to move towards any point which may be selected, and there to establish a base from which to operate in the theatre of hostilities. The "Train", composed of colliers, tankers, supply ships, hospital ships, ammunition ships, repair ships, etc., which are to fill the fleet's material needs at the base, may accompany the fleet or follow close behind. Once the advance base is established, the fleet is independent of the main bases at home for a considerable time, but must of course eventually rely upon supplies being sent from the latter almost uninterruptedly, and must take proper steps to protect vessels engaged upon such service.

Later developments will not infrequently require that a second base be established or that the initial one be moved to another point. Napoleon said that an army "Travels on its belly"; a fleet travels on its bases.

Another question of great strategic importance is that of mobilization. Normally during peace a nation reduces the upkeep of its navy by placing a number of vessels in reserve with reduced crews, and others are put completely out of commission. The supply of stores of all descriptions is kept comparatively low in order to reduce losses from deterioration.

Upon the outbreak of war, or when it becomes imminent, the Navy is "mobilized". That is to say all ships are placed in efficient repair, are fully officered and manned, and are filled with ammunition and miscellaneous needful stores. Following these steps a vessel may require several weeks before she is in proper condition to perform the ordinary functions demanded of a ship in the course of normal and peaceful fleet operations. At least several months of training and drills are necessary before the vessel can be said to be fit to engage in a fleet battle. The interval between the times of first starting to prepare and final readiness is the period of mobilization.

In addition to getting ready the actual fighting ships, mobilization comprehends the collection of a large number of auxiliaries for the fleet "train". These must be chartered from merchant owners, in some cases modified at dock yards for their intended special use, manned by crews willing to enlist and by officers of the merchant service or Naval Reserve, loaded with the necessary stores for their individual use as well as with the cargo to be carried for the fleet, assembled at the designated rendezvous, and organized into an orderly force. It has been estimated that our fleet would require several hundred such auxiliary vessels to properly maintain it in a distant theatre of operations. The shore arrangements for properly and expeditiously loading such a large number of ships, and of administering their subsequent operations after the initial loading, is in itself a large undertaking.

A distinguished Confederate general said in substance that war consisted essentially of getting there first with the most men. To a great degree this is true of Naval Warfare and consequently an early mobilization is of the greatest importance. Should our fleet, for example, be unable to arrive in the Caribbean in advance of an enemy fleet, not only would we miss the great opportunity of engaging our foe before he has arrived at

and secured his base, but we would probably also find the enemy occupying the base which we had planned to use, and consequently our fleet would be forced to choose a less desirable base, and might even be forced itself to accept action before securing its base.

The importance is apparent of fortifying and garrisoning in advance the bases which are essential to successful campaigns in probable theatres of war.

It is almost invariably sound strategy to select as the principal objective of one's own fleet, the main floating forces of the enemy. Eccentric operations, such as raids on the enemy's coasts, bombardments of his ports, the destruction of his merchant marine, the hampering of his commerce, etc., are never justifiable as a principal objective, until after his fleet has been beaten decisively, and such diversions cannot usually be indulged in without a dispersion, and a consequent weakening, of forces, which unnecessarily jeopardizes the true mission of sea warfare. After the enemy fleet is captured, destroyed, or driven from the seas these minor operations may be properly undertaken.

It is also considered precarious strategy to attempt overseas expeditions of large bodies of troops so long as the hostile fleet is "in being", even though the latter be considerably inferior in power to one's own sea forces. This is true because a defeat at sea necessarily means disaster for the land expedition, whose supplies will be inevitably cut off, even should the transports escape destruction before the troops are safely landed.

One of the greatest factors in strategy is information of the position and movements of the hostile forces. Without such knowledge the fleet is rendered impotent; "force" can be utilized effectively only by means of "intelligence" which must have "information" upon which to base its activities. To obtain this prime requisite to success the fleet must depend in great measure upon assistance from shore, where it is customary for great naval powers to maintain at all times a large number of agents scattered throughout the world. In addition it is usually necessary for the fleet to augment such sources of information by other means afloat. Distant scouting is done by large

vessels of great speed and steaming radius. These may be either ships specially built for the purpose or converted merchant "liners". As the two fleets draw nearer, other types of vessels are employed on the very important duty of information getting; first, large and powerful cruisers, then vessels of lesser radius, such as smaller cruisers, destroyers and submarines. Efforts by each side in this manner to obtain information of the other's movements naturally result in converse endeavors to deny information to the enemy and to keep him in ignorance as long as possible. Of course every possible evasion is practiced, and in addition the main fleet is screened to warn it of the approach of the enemy's scouts and to drive them off if possible. These operations lead to minor battles between scouting and screening forces and to the employment of powerful vessels to penetrate the enemy's screens or to prevent one's own screen from being penetrated. Such preliminary contests are on the borderland between strategy and tactics; there being no precise dividing line which can be drawn between these two subjects.

Before leaving the subject of strategy it will be well to consider certain phases of it which are presented after one fleet or the other has gained a decisive advantage. In such a situation the initial aspects of the war have entirely changed. One side, having disposed of its principal objective, has command of the sea and is free then to strike the enemy at a spot even more vital than its sea power.

The policies which brought about the war should still give the cue to future action. Whatever is necessary to put the policies at issue upon a secure and permanent basis should be done. Very often this involves the assistance of the Army. Only the Navy can prepare the way against an overseas enemy; but alone it usually cannot impose the will of its nation upon the hostile country. A resolute belligerent may persist in the war even after its fleet and merchant marine have been destroyed and its ports blockaded against all commerce.

Once the policies for which the war is being fought are considered to be established as well as it is possible to do, then, and not before, should other operations, foreign to it, be undertaken. For example, in the war between the United States and

Spain, the campaign in the Atlantic was at first confined to the establishment of a free Cuba, the policy which precipitated the war. Not until after that was surely accomplished did Porto Rico receive serious attention from the American forces. At about the same time, in order to force a peace, plans were formulated to send a fleet against the remainder of the Spanish navy at home, which would undoubtedly have been done had not Spain indicated her willingness to open peace negotiations.

TACTICS.

The fundamental principle of war which governs both Strategy and Tactics is the concentration of the mass of one's own forces against weaker enemy detachments at crucial times and at critical places. The importance of time and of place from the strategic aspect has been already discussed. Emphasis has not been laid upon the advisability of superior concentration upon enemy detachments, only because it is obvious and well understood that a strategic separation of main forces whenever the near presence of an enemy renders defeat in detail even remotely possible, must greatly jeopardize success. So important is this principle that as a rule, even in time of peace, the major units of a fleet are kept near enough together to ensure ready concentration should war become imminent. Of course in the conduct of hostilities the imperative necessity for getting information leads to the advancement of scouts; but, as has been already explained, these consist of very fast vessels whose speed favors immunity against serious losses until the two main bodies draw near enough together to permit support to the scouts by more powerful ships.

The advent of the destroyer, against which defense at night is very difficult, has led to a new application of the principle of concentration. Many tacticians consider that the destroyer attack should be launched during the night preceding the prospective day engagement. This amounts to attacking the enemy in succession, which is somewhat at variance with the cardinal principle of concentration, yet the advantages to be gained by damaging some of the enemy's major units (the battleships) before they can take part in the main battle, with the consequent reduction of his material forces as well as the

lowering of his morale, are so great as probably to justify this modification of the fundamental principle. A parallel of thus attacking in succession is to be found on shore when the main infantry attack is preceded by an artillery bombardment. On the other hand there are advocates of withholding the destroyer attack until during the day battle, when an enemy under gun fire is loath to divert his own gun-fire from the opposing battleships in order to ward off a destroyer attack. Not only is this latter method more in keeping with the principle of concentration, but it also takes into account the possibilities of the destroyers failing in the darkness to find their prey and perhaps getting lost or widely separated from their own main body in the effort to do so. Moreover it discounts the probability of suffering severe losses from the enemy's screening vessels at night and thus diminishing the effectiveness of the destroyers during the succeeding day battle, which is without doubt the crucial time and place to make the maximum concentrated effort against the foe.

The problem of the employment of submarines is somewhat similar. Their effectiveness if successfully used during the gunnery duel between the battleships will be greater than if employed in previous minor eccentric operations. But on the other hand their characteristics of low speed, invisibility, invulnerability, great difficulty of concentrated action, and indifferent periscopic vision, render them better suited to the role of stealthy individual effort than to that of coördinate action with a large fleet.

Probably the decision as to which method to employ with both destroyers and submarines will be determined in each case by the particular conditions governing the approach of the two fleets and their relative strength. Should each fleet establish itself in a base close to the other before a major battle has been fought, probably minor operations by destroyers and submarines will be adopted by both sides with a view to reducing the battleship strength of the enemy, while keeping their own battleships in such security as the port may offer.

Should one fleet have the advantage of awaiting in its base the enemy's approach from a distant point to the theatre of operations, the former, particularly if it be the weaker in battle-

ships, will probably employ its destroyers and submarines, unsupported by battleships, in an effort to reduce the enemy's battleship superiority. Should the advancing fleet, however, possess an overwhelming superiority in cruisers, the difficulties of the attacking destroyer would be great; not only because of the danger of annihilation, but also on account of the improbability of getting timely and accurate information of the enemy's location from their own weaker force of cruisers; and without such information a successful destroyer attack is extremely difficult.

In such preliminary secondary warfare the submarine mine must inevitably play an important part. It will be used defensively by battleships in port to prevent the hostile submarines from attacking them in their base, and also offensively by destroyers and fast cruisers, to assist in the damage to and the demoralization of fleets under way. In the former case the anchored type of mine will be used, and in the latter case the floating type.

The Main Day Action.

After the introductory minor warfare, the two fleets disputing with each other the command of the theatre of operations must inevitably clash before the issues which brought about the war can be decided; either on the sea or subsequently on land.

The principal objective of each force is the annihilation of their opponents as an organized and effective fighting machine. Experience shows that unless such objective is clearly formulated and understood in advance, the battle is apt to be indecisive and fruitless.

Concentration of superior force at the decisive point at the critical time is always the key to success. The mere possession of stronger and more numerous units is no guarantee of victory unless the superiority is employed in a concentrated form at the proper time. In the effort to accomplish this lies the essence of all tactics. Reserves have no place in a sea fight; the entire force should be brought into action as nearly simultaneously as possible, so distributed as to afford mutual support, and if practicable in such manner as to isolate a part of the enemy from the battle while the remainder is being defeated.

Under modern conditions the gun is the principal weapon of the main type of ship—the battleship. Owing to the rapidity of gun-fire and to the fact that each hit reduces the enemy's offensive power, any initial advantage gained increases very quickly. With equal units naval gun power varies as the square of the number of guns or ships. Hence the vital importance of time in a sea fight is obvious. A superior concentration of gun fire for only a few minutes at a critical point may be sufficient to decide the issue, even though considerable re-inforcements may be just about to come into range. Nelson said that "time is everything" in a sea fight and that "five minutes" may make the difference between victory and defeat. Since Nelson's age the speed of ships and the rapidity of gun-fire have increased very much, and the importance of the time element has grown greater accordingly.

The influence of the gun is also paramount in the formation which fleets are led to adopt. The number of guns which can be brought to bear in "broadside fire" is necessarily greater than in "end on fire"; consequently the natural formation to be taken for battle is a line of vessels each presenting its broadside to the enemy. This is the conventional formation; but several influences tend to make such an alignment only approximately exact and symmetrical. In the first place the difficulties of position keeping, particularly during battle, are very great with such large vessels as are now built. Then too, the ends of the line being obviously weak are frequently the object of attack, which may induce the leading vessels to turn away from the threatened danger. Should each vessel in rear follow in wake of the leader, a "knuckle" is caused in the line which invites the enemy's concentrated fire and may result in a decided advantage to him. Differences of designed speed between various battleships and the length of time necessary for a long line to complete a change of course also operate to induce an Admiral to choose an alignment of groups as the battle formation rather than one of single vessels.

Nelson's maxim that "the less maneuvering the better" still holds true, because maneuvering not only tends to produce confusion in the fleet and distraction from fighting but it also seriously interferes with gun-fire. The process of repeatedly

correcting gun-fire from the fall of shots until the battery is hitting is quite difficult, and once it is accomplished any marked change of course or speed necessitates repeating the range-getting operation; then too the time taken to turn or to change speed is considerable, and while it is in progress fire is rendered inaccurate from the turning vessel, without greatly affecting the accuracy of fire from her opponent.

Nevertheless some maneuvering must be done. Because of the ragged formation to be expected, as well as the uncertain factor in signalling, a simultaneous movement of all ships in the line is considered by most officers to be dangerous (on account of probable collision) and impracticable of execution by a large number of ships engaged in battle. As has been already pointed out a change of direction accomplished by each vessel turning in succession in the wake of the leader is slow and is accompanied by a gun-fire handicap. The most approved method of maneuvering during battle is known as ''division column movements''. By this plan the fleet of battleships is subdivided into small groups of from three to five vessels, the leading one of each subdivision maneuvering by a prearranged plan, or in accordance with signals made from the commanding Admiral's flagship, and the other vessels within a group following in the wake of their group leader.

Two fleets approaching endeavor to preserve their ''line of bearing'' (the imaginary line passing through each unit, or through each group leader, as the case may be) about at right angles to the bearing of the hostile force. In this manner the distance between the fleets can be rapidly lessened until within gun range, and then by a quick maneuver the formation can be changed so as to swing the broadsides of all ships to bear upon the enemy. The result is an alignment in which the course steered coincides approximately with the ''line of bearing'', both then being about perpendicular to the bearing of the enemy.

The well known weakness of the flank makes it very desirable to bring a fleet into action with one's own fleet broadside presented to one of the hostile flanks. In this situation, known as the ''T'', the guns of the entire fleet may be concentrated against two or three of the flank vessels of the enemy while his

return fire is limited to the bow or stern fire of a few flank vessels. This is the ideal tactical concentration; its effect is obviously fatal to the fleet presenting only a flank to its enemy, and within a short time its ships will be sunk in rapid succession. Except when completely surprised, as might happen for example by the lifting of a fog, such a concentration can be rarely effected, although approximations to it are invariably striven for and have been attained in past naval actions. A fleet badly handled, or one incapable of efficient interior maneuver, may easily be caught with an approximate "T" against it, either at the opening of or during a battle; the Russians had this misfortune at Tsushima, and the penalty of their tactical blunders in that fight could not have been redeemed by the most wonderful gunnery in the world. It is also possible, provided the slower fleet continues on an unchanged course, for a faster fleet to draw ahead from the normal parallel position, and to eventually attain the "T" against its slower opponent. It is however so extremely easy for the slower fleet to merely turn its head, a little at a time and without affecting its own gunnery, away from the faster antagonist, that superior speed in such situation is not a great advantage. It is this consideration which has led some designers of battleships to limit their speed to a moderate figure and thus permit a more powerful and numerous battery and better armor protection, to be installed.

On the other hand the great advantage of the flank position has induced England, Germany and Japan to build a type of vessel called the "battle-cruiser". It possesses extreme speed, about 30 knots as compared with about 21 for battleships, has a moderate amount and thickness of armor, and carries a few of the largest type of gun. These vessels are very valuable in reconnaissance work, being fast enough to run away from the only vessels superior in gun power; are sufficiently strong and fast to run down and destroy anything less than a battleship; and their great speed combined with heavy, long-range guns makes of them a serious menace to the flank of a fleet of hostile battleships. The battle-cruiser, however, costs as much as a battleship and it is questionable whether the money necessary to build it is not better expended in a ship of greater power and protection even though it has considerably less speed.

This latter view is the one so far taken by United States designers.

The battle-cruiser is usually given a powerful torpedo battery which compensates in some degree for its deficiency in gun power. Its high speed makes it an excellent torpedo carrier.

The ideal position from which to start a torpedo attack is one beyond the gun range and well in advance of the enemy's fleet, though not directly ahead of it. To be more exact the torpedo attackers should bear from the leading ship of the enemy about 20 degrees from ahead. Once in this position, torpedo range, which is less than gun range, may be reached very quickly and therefore with the least danger from the hostile gun-fire, by steaming towards the enemy; the speed of approach then being practically the sum of the speeds of each force. The above mentioned position in advance is best not only because of the advantage of a relatively short time under fire from the enemy, but also on account of the increase in the distance from their target at which the torpedoes may be discharged from the attacking vessels. This increase is due to the fact of the target steaming in a direction approximately towards the torpedo during the time taken by the torpedo's run. Such conditions may result in an effective range of a torpedo, as much as 30 or 40 per cent greater than the actual distance which the torpedo is capable of running. Obviously such a gain is an exceedingly important factor in the success of a torpedo attack when it is considered that probably the operation must be carried out in the face of a heavy fire from the enemy's guns.

A torpedo attack in force upon the head of a fleet already under gun-fire from an enemy is a very serious menace. The fleet so threatened must choose between maneuvering to avoid the attack, diverting its gun-fire from the opposite battleships to the torpedo attackers, or submissively receive the attack, trusting to luck that the torpedoes will miss. Any one of these three courses of action is very dangerous and will probably decide the battle in favor of the side which is directing the torpedo attack. Consequently, in a day action it becomes the chief object of all torpedo carriers, such as battle-cruisers, other cruisers, destroyers and submarines, to reach the position pre-

viously mentioned as favorable to torpedo attack (nearly ahead of the hostile fleet) as early as possible and to deliver the attack soon after gunfire has begun in earnest. Should it be attempted too soon, that is before the two fleets have each other under heavy gunfire, the enemy will merely turn away without suffering the penalties of such a move, and thus completely frustrate the torpedo attack.

It follows as a matter of course, since the torpedo carriers of both fleets desire to occupy the same general area, that a fight between them may be expected, with a double view of protecting their own fleet from torpedo attack and of executing such an operation against the enemy. In this secondary fight the destroyers will be supported by cruisers, many types of which do not carry torpedoes, and the former will as far as possible avoid the minor conflict and carry through their principal mission of delivering their torpedo attack against the hostile battleships in good season. A fleet which is weak in cruisers may be impelled to send forward a few of its faster battleships with a view to dominating the important area in advance of the fleets.

COMMAND.

It can be readily understood that the direction or management of such operations as have been described must be conducted with a high degree of expertness if success is to be attained.

As has been indicated, sound strategic plans require as their source a comprehensive understanding of national policies. The task of reaching such an understanding, more especially when the policies have not been given clear and explicit definition and must consequently be approximately deduced in advance from a study of national interests, is one demanding a high degree of special qualifications, such as those which Admiral Mahan by his writings indicated that he possessed. Qualifications of this nature are difficult for a naval officer to acquire, and probably more so for a layman, but it is obviously important that someone occupying a responsible position should be trained in this field, and in self defense the Navy must sometimes undertake the work for its own purposes and

be governed by the resulting deductions until a more authoritative expression of policy is promulgated.

Strategic plans for war should be prepared with great care and deliberation during the calm of peace. Besides a study of international conditions and politics, to determine the particular policies which may be jeopardized, they require exhaustive studies from every aspect of the probable theatres of the war. The relative strength, present and future, of our own navy and that of the probable enemy, must also receive careful consideration. The questions of sources, means, and routes, of supplies —both material and personnel; of obtaining information and distributing it to the proper destinations; of the selection and defense of bases; of the possible movements of our fleet in relation to that of the enemy; of organization ashore and afloat; of mobilization; and of many other matters which need not be specified, all require the most exhaustive study, and the conclusions reached must be constantly revised and kept up to date.

All of these matters must not only be studied and developed separately but coördinately as well, so that all parts of the plan will harmonize.

Tactical plans require an equal measure of mature consideration. They should be based upon the strategic plans. Types of ships and of weapons are constantly undergoing change, and conceptions, organizations, and plans must be governed accordingly. The personnel, both men and officers, require unceasing training in the most approved methods, not only afloat but also in the shore establishments which serve the fleet.

One very essential part of the training of personnel is what is known as ''indoctrination'', that is the creation of a school of thought, a bond of understanding, which will favor coördinate action by all branches of the service under any circumstances that may arise. Such mutual understanding is desirable during strategic operations; because then forces are widely separated and communication between them may be precarious and slow. But more especially is it desirable during tactical operations. In battle between two large fleets it is impossible for the Commander-in-Chief to personally observe or direct the individual movements and conduct of each ship. If such were possible, tactical proficiency would be greatly facilitated, be-

cause then the action of each ship would harmonize with all the rest, and unity of action would result. But unless the Commander-in-Chief takes station in an air craft he cannot survey the entire field nor can he otherwise eliminate aggravating parallax from his view even for that part within his range of vision.

Another serious drawback under which the Commander-in-Chief must labor, no matter what disposition may be made to improve his perspective and vision, is the difficulty of rapid and accurate communications. Flag signals are slow and not visible very far. The radio (wireless) is liable to interference from the enemy, and is also too slow.

When depending wholly on the imagination it is difficult to conceive of the dominating influence of time upon naval battle; the various groups of different type moving at high speed create constantly changing situations, many of which are pregnant with possibilities for victory or defeat for the entire force. To take proper advantage of an opening, or to recover from a disadvantageous position, it is normally imperative that commanders of ships and divisions decide and act immediately—without waiting until the Commander-in-Chief can be informed and his instructions in reply can be received; because otherwise each movement would be too late to accomplish its initial purpose.

The inherent weakness resulting from uncoördinated and dissipated efforts, and the manifest necessity for united action, naturally suggest that the Commander-in-Chief issue a plan previous to the battle, to which all can conform. This is, or should be, invariably done. But in the nature of things it must be limited to very general matters and principally to the opening of the battle. The possible combinations that may be made, and the great variety of situations that may result from the fact of the enemy being a free agent, make it wholly impracticable to anticipate in a plan every situation that may arise, and an attempt to do so would necessarily result in a document so voluminous as to defeat its own ends by producing confusion rather than order.

For both strategic and tactical purposes, therefore, a bond of mutual understanding, technically known as "Doctrine", is

essential to timely and effective coördination and unity of action.

The task of creating doctrine is very laborious and difficult. If it is to fulfil the mission for which it is designed, doctrine must obviously be up to date, comprehensive, and applicable to any situation that may arise.

The true basis of doctrine is a conception of modern war. To formulate such a conception in a satisfactory manner it is necessary to first exhaustively study and analyse most of the previous naval campaigns and battles of which history gives a satisfactory record; then there must be taken into consideration the unchanging principles of war as well as the latest types of ships and weapons and all other conditions likely to be met in the particular wars for which plans are to be made. In addition it is essential that many practice maneuvers, both on the maneuver board and with actual ships on the water, be conducted and the result analysed.

The process of creating a comprehensive conception and of keeping it up to date is an evolution which never ceases and requires the constant attention of a reflective body of officers possessing the highest attainments working in conjunction with the fleet when engaged in maneuvers. It can best be done by a General Staff.

From the basic conception there may be deduced various doctrines essential to the "bond of mutual understanding" and to unifying professional thought and action upon all fundamentals; whether they relate to the shore or floating branches of the service.

Due to the more beneficial effect upon morale it is preferable to convince the body of officers at large of the inherent soundness of the chosen doctrines, rather than to dogmatically impose them upon the service. This task is one also properly belonging to a General Staff; when it is accomplished, the personnel is said to be "indoctrinated" which in a few words means that they are prepared to operate together coördinately without the necessity for orders in any other than a very general form.

As has been indicated, the process of indoctrination embraces that of education and training and aims eventually at

allowing subordinates great discretion. But before subordinates can be safely entrusted with a large measure of discretion and initiative, they must also possess wholehearted loyalty; not so much to the person in authority as to his expressed general plan. Before united and effective action is possible, the desire for personal glory and the inevitable differences of personal opinion must be unquestioningly subordinated to loyalty to the plan which furnishes the basis of action by the organization as a whole. It is an important part of the function of command to stimulate and foster loyalty, which is the keystone of coöperation.

Finally, and most necessary of all, command must endeavor to inculcate a high "morale" which may be defined as confidence combined with an ardent desire to do the utmost. Of this factor in warfare Napoleon, the greatest master and most profound student of war in all history, said "In war the moral is to the physical as three to one".

Battle is first of all a contest of character; victory will come to the side which can longest sustain the will to attain it together with the belief of ultimate success. The stimulation and preservation of such qualities in the personnel should invariably be the chief concern of those in authority. To do so successfully requires of them a knowledge of psychology together with a thorough understanding of human nature in the particular form to be found among those comprising their subordinates.

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Paper No. 210

MARINE STEAM BOILERS AND BOILER ROOM EQUIPMENT.

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During the last decade there has been a considerable development and improvement in marine boilers, both of the Scotch type and of the water-tube type. The changes, however, in design and improvement in efficiency have been less marked than the great changes in marine propelling machinery, in which the steam turbine has largely replaced the reciprocating engine in naval work and in much of the merchant work. This condition is now being modified by the fitting of speed-reduction devices. In submarine boats, a number of other naval vessels and in some merchant vessels, the crude-oil engine is being adopted.

By comparison, therefore, the developments in marine boilers appear to be overshadowed, as no radically new principles have been adopted in practice, although several notably conspicuous new inventions have been made which may develop in the future. Among these should be mentioned the Bone surface-combustion experiments, the mercury boiler, invented by Mr. W. L. R. Emmet, the Talbot high-pressure boiler, which has been used in small units with much success, and the Bettington powdered-coal boiler.

The efficiency of marine boilers has been generally improved due to the following causes: A more careful study of conditions governing combustion in the boiler and means for quick analysis of the products of combustion and for observing the variation of temperatures throughout the path of the gases; the study of heat transfer, in which is involved the volume of the combustion chamber, baffling of the gases, and arrangement of

passages for same, tube spacing, disposition of the heating surfaces, circulation of the water, liberation of the steam, cleaning of the heating surfaces, both on the fire side and on the water side. Steam pressures cannot be said to have generally increased excepting in some particular instances.

In addition to the foregoing, there should be mentioned the revival of interest in superheated steam, which bids fair to largely increase and which promises considerable gain in overall efficiency. Oil burning has developed to a high degree of perfection both with steam and air atomization, and notably with mechanical spraying. The study of corrosion has occupied considerable attention.

Improved workmanship is recognized as an important factor in ultimate boiler efficiency, and along with this may be noted the advance in shop facilities for working the materials and tools for more accurately and rapidly machining the finished parts. This has led to the standardizing of many details which have been most carefully designed for assembly, or replacement, durability, reduction in weight, improvement in appearance and facility of manipulation.

The use of the oxy-acetylene flame for cutting materials, the use of electric welding, especially for repairs, and the extensive adoption of pneumatic tools have had a material effect in improving the quality of boiler work and reducing the cost of construction and upkeep.

Advances have been made in mechanical draft, feed purification and supply in the handling and disposal of refuse and ashes; fire room communication; and time indicator firing has been largely adopted in the highest-grade work. These various minor improvements have resulted in a considerable gain in efficiency and reduced cost of upkeep.

The increase in size of marine boiler installations is one of the most striking recent advances, and along with this increase is to be noted some decrease in heating surface per horse power, which is largely due to reduced steam consumption of the propelling machinery and partly due to a higher boiler efficiency and dependability. In naval work the use of oil fuel only, or oil and coal combined, has reduced the heating surface to a more marked degree. Boiler installations of over 100,000

horse power per ship are now made, whereas ten years ago powers of 20,000 to 30,000 horse power per ship were about the maximum.

SCOTCH BOILERS.

The changes during the past decade in the Scotch type of boiler and other fire-tube boilers have been less than in most forms of water-tube boilers.

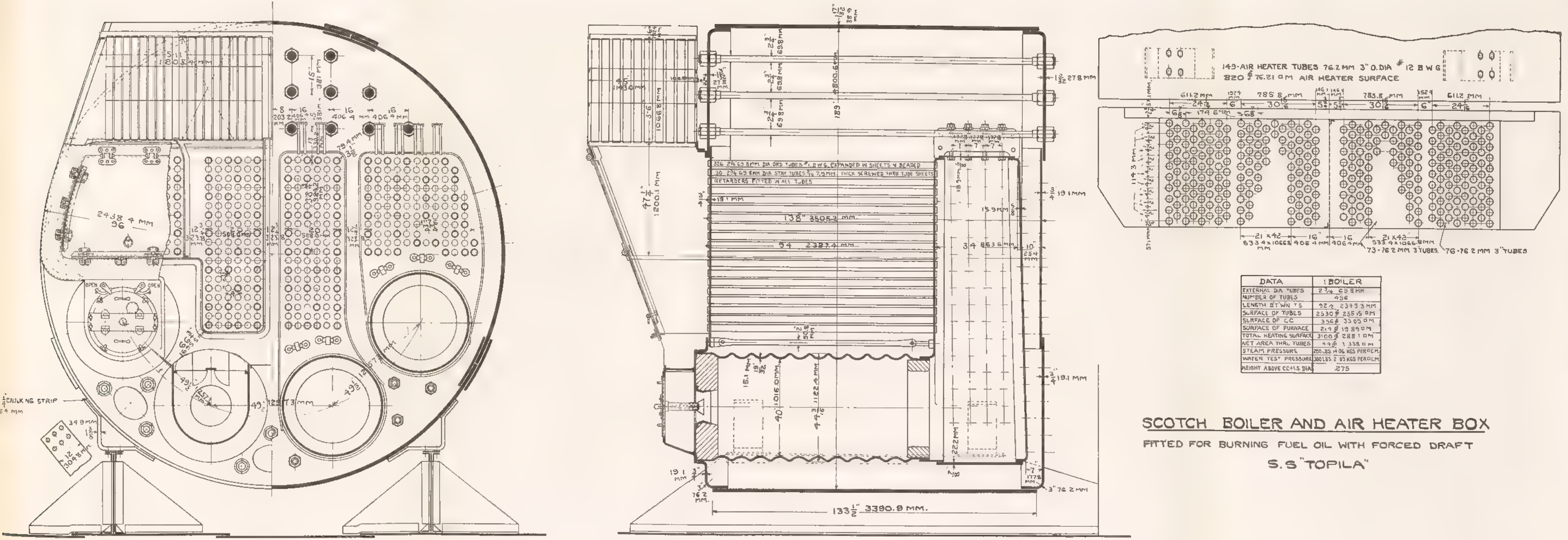
We note simplification in design due to the modern rolling-mill facilities for supplying larger plates, thus reducing the number of seams. It is usual now to construct single-end Scotch boilers up to 12 feet (3660 mm.) in length and nearly 18 feet (5486 mm.) in diameter with no middle circumferential seam and with only one seam across the back head. Separate combustion chambers are usually fitted in single-end boilers and also in double-end boilers in connection with forced draft. With natural draft or assisted draft, in double-end boilers, it is not unusual to connect the corresponding furnaces in opposite ends of the boiler to straight through combustion chambers; this considerably reduces the length and weight and simplifies the construction. When such combustion chambers are fitted, fire-brick walls are sometimes built up in the middle between the furnaces.

The combustion chambers for double-end boilers are usually tied to the bottom of the boilers to prevent working when steaming, although with single-end boilers it is not essential to tie the chambers down.

The lower wrapper plates of the combustion chambers are sometimes made in one plate of greater thickness at the bottom part where unsupported by stays, thus saving the side riveted laps.

The question of material of boiler tubes is one on which there is a considerable difference of opinion. The best charcoal iron tubes and seamless drawn steel tubes seem under favorable conditions to give equally satisfactory results. The use of Serve tubes in Scotch boilers has practically been discontinued. With water-tube boilers it is common to use seamless drawn steel tubes.

It is now usual to fit the back ends of the corrugated fur-



DATA	1 BOILER
EXTERNAL DIA TUBES	2¾ 69.8 MM
NUMBER OF TUBES	456
LENGTH BT'WN T.S.	92¼ 2343.3 MM
SURFACE OF TUBES	2530 ☐' 235.15 ☐M
SURFACE OF C.C.	356 ☐' 33.09 ☐M
SURFACE OF FURNACE	214 ☐' 19.89 ☐M.
TOTAL HEATING SURFACE	3100 ☐' 288.1 ☐M
NET AREA THRU TUBES	4.4 ☐' 1.338 ☐M
STEAM PRESSURE	200 LBS. 14.06 KGS PER ☐CM.
WATER TEST PRESSURE	300 LBS. 21.09 KGS PER ☐CM
HEIGHT ABOVE C.C.+I.S. DIA	.275

SCOTCH BOILER AND AIR HEATER BOX

FITTED FOR BURNING FUEL OIL WITH FORCED DRAFT

S. S "TOPILA"

Fig. 1.

naces either of the horse-collar type, the straight type or of some form of flanged type which permits of the furnaces being renewed at a minimum expense.

It is not uncommon to fit Scotch boilers of very large dimensions. The boilers of the S. S. "Aquitania" are 17′-8″ (5385 mm.) mean diameter by 22′-0″ (6706 mm.) mean length.

Some owners take precautions to prevent air drafts from circulating at the bottoms of their boilers, and lag the bottoms with asbestos or magnesia blankets or pads which are easily removed for examination. This is an excellent practice, promoting economy in operation and upkeep.

The ordinary plate saddle or support is largely used for Scotch boilers in conjunction with fore and aft chocks. A form of Scotch boiler support which is frequently adopted by American builders is illustrated in Fig. 1. These supports consist of heavy bent steel lug plates riveted to the lower shell of the boiler, each lug being fitted with a ¼ in. (6.3 mm.) caulking plate adjacent to the shell. These plates can be hydraulically riveted when the shell riveting is being done. Girders are fitted in the ship, as indicated in Fig. 1, to which the lug plates are bolted. Provision is made at one end of the boiler for expansion. Similar supports are also common for Yarrow boilers. All boiler supports should provide the greatest facility possible for care of the lower parts of the boiler. It may be noted that the heating surface per cubic foot volume of boilers has not altered materially, but the tendency is to allow more steam space, which gives better access for cleaning and care.

WATER TUBE BOILERS.

The recent developments in the design and construction of marine water-tube boilers have been much more pronounced than in Scotch boilers. Many of the early errors in design have been eliminated, so that high efficiencies are now common, both in naval and merchant work.

The requirements demanding the best material and workmanship have been recognized and now many of the water-tube boilers are examples of the finest product of skilled designers and workmen and modern machinery and methods. In this connection it is interesting to refer to the early influence of

Mr. A. F. Yarrow, who, in 1891,* pointed out that only the best materials and workmanship should be employed in boiler work.

Boilers of the Babcock and Wilcox, Niclausse, Bellville and Yarrow types have all retained their essential features for the last ten or fifteen years. Many of the other so-called express types of boilers have been merging towards a more or less composite design in which the objectionable features have been largely eliminated.

Boilers which a few years ago were fitted with tubes having extreme bends are now made with these tubes of gradual bends, and in some cases, the tubes are straight with the exception of the lower ends entering the water drums. The upper ends of the tubes are now usually submerged and arranged to facilitate cleaning and inspection; air pockets are generally avoided as it has been found corrosion is active at these points. The straight-tube type of boiler, represented by the Yarrow, fits the rows of tubes next to the fire with slight bends to allow for expansion. Steam drums are of larger diameter in the three-drum, or express type of boiler, than in the Babcock and Wilcox or the Niclausse boiler, due to structural reasons, accessibility, and to provide a good volume of water.

The water pockets at the lower ends of the tubes are approaching the circular section and in some cases the oval or D-drum has been replaced by the circular drum.

Due to these improvements, resulting in great reliability and increased durability, the heating surface for naval work, especially where oil fuel is used, has been notably reduced.

The water-tube boiler has been adopted for practically all naval vessels, excepting auxiliaries such as colliers, where Scotch boilers are used in some cases.

The German Navy uses the Schulz or Schulz-Thornycroft boiler nearly exclusively for all sizes of vessels. Other navies are using two or more types of boilers, principally as follows:

England—Babcock and Wilcox and Yarrow for large vessels. Yarrow and White Forster for smaller vessels and destroyers.

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* Paper on Construction of Boilers Adapted to Forced Draught, Institution of Naval Architects, 1891.

France—Bellville, Niclausse and Guyot Du Temple for large vessels; Normand and Lagrafel d'Allest, Du Temple Guyot and White Forster for small vessels and destroyers.

Italy—Bellville, Niclausse, Blechynden, Babcock and Wilcox and Yarrow for large vessels; Thornycroft for small vessels.

Japan—Yarrow, Bellville, Niclausse, Miyabara and Babcock and Wilcox for large vessels. Miyabara and Yarrow for small vessels.

United States—Babcock and Wilcox and Yarrow for large vessels. Babcock and Wilcox, Yarrow, Normand, Thornycroft and White Forster for intermediate vessels and destroyers.

Thus it is seen that a wide range in type of boiler is still being allowed by naval authorities. The requirements in boiler installation which appeal to one nation as most essential appear differently to another, and doubtless properly so, as the broadest view of ultimate efficiency should be taken, into which enter a consideration of the home facilities for building, replacing or repairing in the most expeditious manner. Thus the fine shops in Great Britain and the United States for expeditiously building the Babcock and Wilcox boiler and the corresponding facilities in France for constructing the Niclausse boiler and the absence of such special works in Japan, may influence the Japanese Admiralty in adopting in a home-built vessel the Miyabara boiler or some other type which may be constructed with the shop facilities at hand.

It is to be noted that the sizes of water-tube boiler units have greatly increased. The efficiency of the large units is higher than that of the small units, especially with oil firing.

In installations of the small tube boilers for large powers it is usual, in English and American practice, to provide considerable more heating surface than with installations of Babcock and Wilcox boilers. In making comparisons between boilers on the basis of heating surface this point should be borne in mind.

Water-Tube Boilers in Merchant Vessels.

In considering the installation of water-tube boilers in trans-ocean or coasting merchant vessels, the question of proper facilities for cleaning the boilers during long voyages must be kept in mind. Many boilers which show high efficiency under shop

tests may fail under the severe conditions of service in merchant shipping, where long voyages are made, changing weather conditions are encountered and the quality of coal is sometimes inferior. The operation of merchant vessels is often attended with limited time in port for over-hauling, repairs and cleaning. Some large installations of water-tube boilers have been made in merchant work which have not given the satisfactory service anticipated, owing to the lack of facilities for properly cleaning the fires, sweeping the heating surfaces, regulating the air to the furnaces, and ventilating the stokeholds. Such installations do much to retard the introduction of water-tube boilers in the merchant marine. The Babcock and Wilcox boiler has probably been installed in a greater number of mercantile vessels than any other type of water-tube boiler, and its success has been largely due to the characteristics outlined by the late Rear-Admiral George W. Melville,* formerly Engineer-in-Chief, U. S. Navy, in an article in which he says:

"From my study of the subject, I had reached the conclusion that the thoroughly satisfactory watertube boiler should possess, among others, the following characteristics:

"Reasonable lightness, with scantlings sufficient to promise reasonable longevity;

"An adequate amount of water, so that failure of the feed supply or any inattention thereto would not immediately cause trouble;

"Accessibility for cleaning and repairs on both water and fire sides;

"Straight tubes, with no screw joints in the fire, but the simple expanded joints so well tested out for years;

"No cast metal, either iron or steel, subjected to pressure;

"Ability to raise steam quickly;

"High economy of evaporation;

"Economy of space;

"Interchangeability of parts, and, as far as possible, the use of regular commercial sizes so that repair material could be procured anywhere;

"The ability to stand severe forcing without injury;

* "The Development of the Marine Boiler in the Last Quarter Century", Engineering Magazine, January, 1912.

"The ability to stand abuse—that is, to be of rugged construction and not so delicate as to require skilled mechanics to run it;

"Safety against disastrous explosion, meaning that only the part of the boiler which gave way would be damaged."

Higher efficiencies can often be obtained with well-designed water tube boilers than with Scotch boilers, principally owing to the fact that the furnace is large, its form may be nearly ideal for thorough combustion before the gases enter the tubes; whereas in Scotch boilers, the furnaces are contracted and low and the combustion space is completely surrounded by the cooler boiler surfaces.

Experience in the merchant vessels "Creole", "Matsonia", "Adeline Smith", and several others, each operated by different owners and fitted with Babcock & Wilcox boilers, indicates that with a reasonably intelligent engineering staff, boilers of this type are thoroughly reliable and can be operated at a lower cost of maintenance and are more flexible, and probably more efficient, than ordinary Scotch boilers. In the "Adeline Smith", fitted with four boilers, there has never been a delay of any kind for cleaning or minor repairs; one of these boilers can be cooled sufficiently to work in within an hour or two, and steam raised again in forty-five minutes.

The writer is informed in regard to the six Babcock and Wilcox boilers and three single-end Scotch boilers installed in the steamer "Matsonia", and using oil fuel, that very little cleaning of the water-tube boilers is necessary and that it is not required to mechanically clean the tubes oftener than once in two or three months. No signs of corrosion have appeared. The zinc plates are renewed approximately each six months. A half keg of Renown compound is also used per trip of 2000 miles. It is not found necessary to have higher-grade men in the fire room to operate these boilers than those ordinarily operating Scotch boilers. Feed-water regulators are desirable and the Hough patent feed check valve is considered a necessity where reciprocating feed pumps are used.

The Matson Navigation Company's purpose in installing a combination of Scotch boilers and Babcock and Wilcox boilers in this vessel was that they might have Scotch boilers for winch

work in port, owing to the larger steam space. They find, however, that a number of steam schooners fitted with only two Babcock and Wilcox boilers have no boiler troubles even though using them constantly in port for donkey boiler service.

The saving in weight and space which may be effected with water-tube boilers over that required for Scotch boilers is great, as shown by Admiral Melville in his paper.

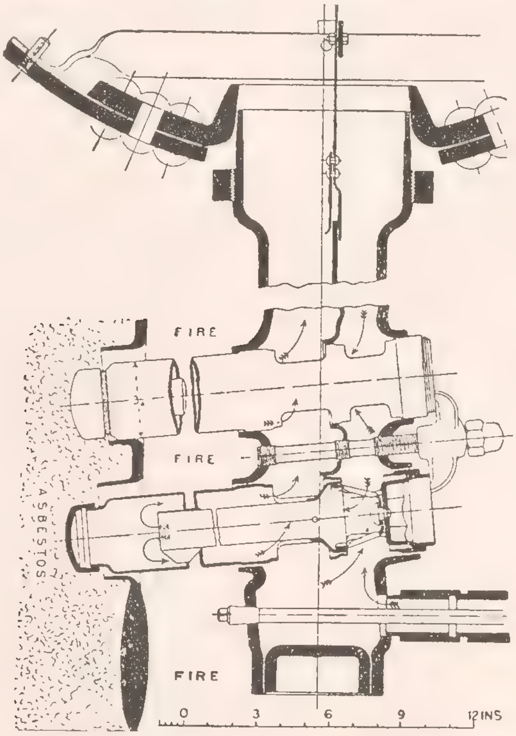


Fig. 2. Niclausse Boiler.

The Niclausse Boiler.

This well-known boiler, which has been largely adopted by the French Navy and others, has retained the essential principles of its unique construction, but recent improvements have resulted in a very high efficiency.

These improvements, some of which have been in use a considerable time, include the following:

Constructing the headers of solid drawn pressed steel of larger rectangular section.

Making the tubes solid drawn with swellings to form the cones and lanterns.

The adoption of a system of forced circulation and feed distribution to the lower tubes which are nearest the furnace, which also includes arrangements for purifying the feed.

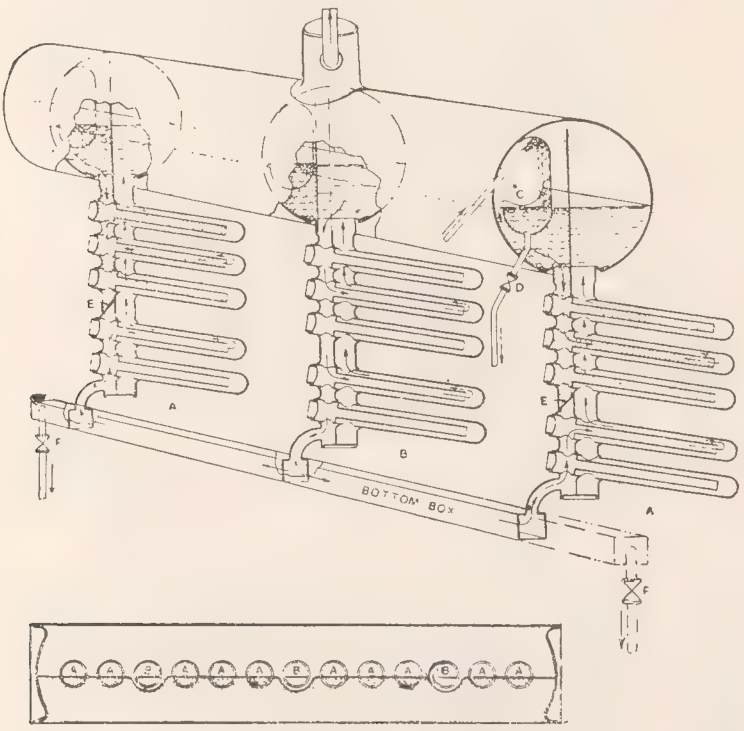


Fig. 3. Niclausse Boiler.

All of these points are described in a paper by M. Niclausse* and records are given of a test by naval officers of the boiler as proposed for the new French Battleship "Béarn".

Figures 2, 3 and 4 indicate the arrangement and some details of this high-duty Niclausse boiler.

White Forster Boiler.

As is well known, the distinctive features of this boiler are the adoption of a uniform curvature of all of the tubes in any

* Paper read before the Mechanical Engineers at Paris, July 8, 1914, and published in "Engineering" July 17, 1914.

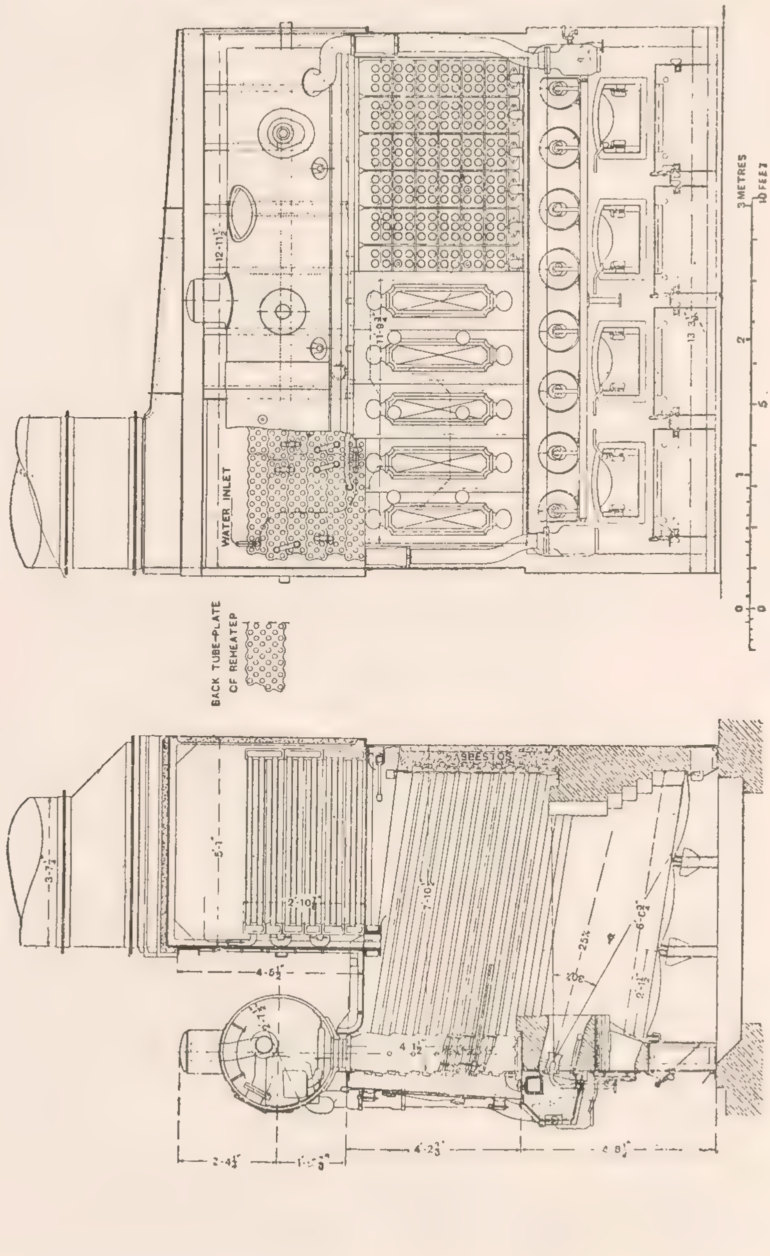
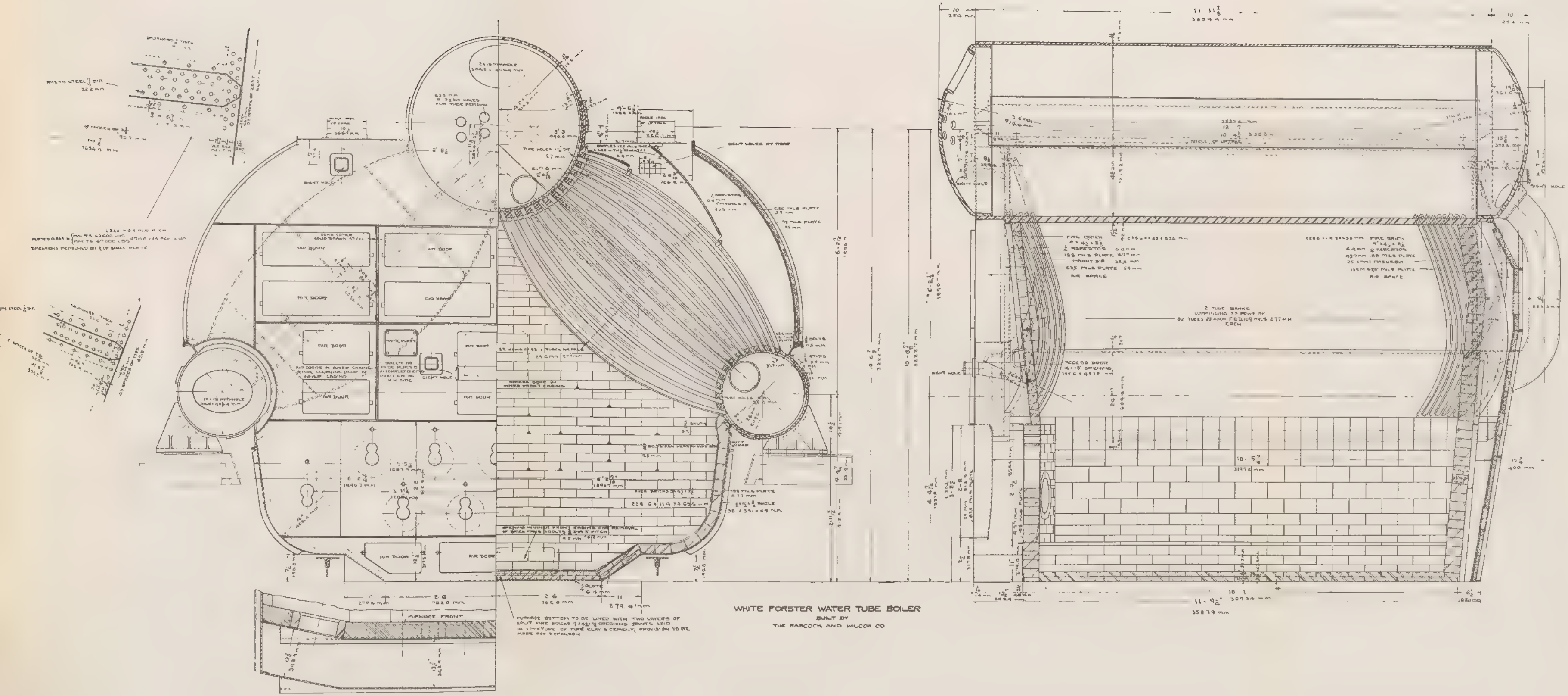


Fig. 4. Niclausse Boiler.



WHITE FORSTER WATER TUBE BOILER
BUILT BY
THE BABCOCK AND WILCOX CO.

Fig. 5.

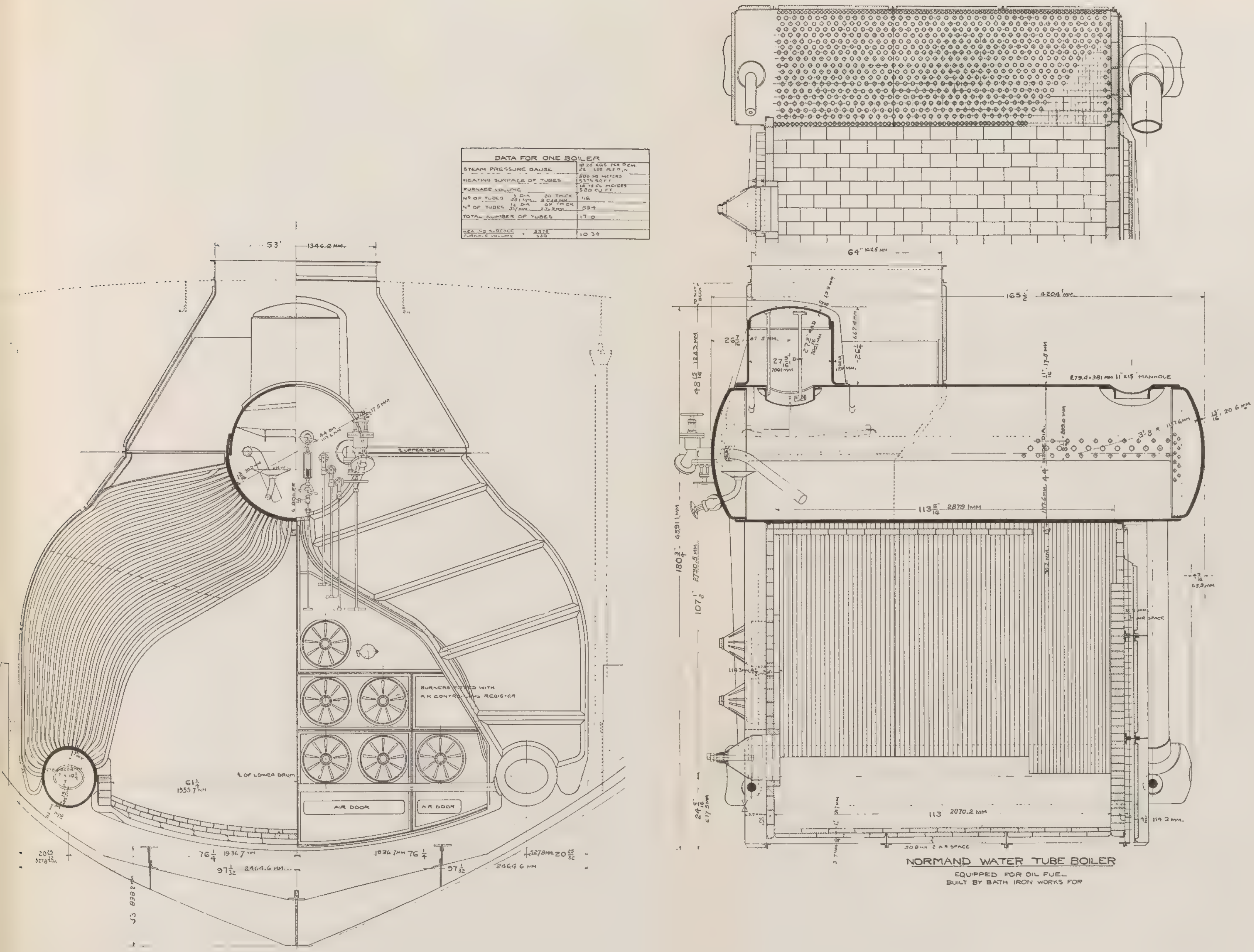
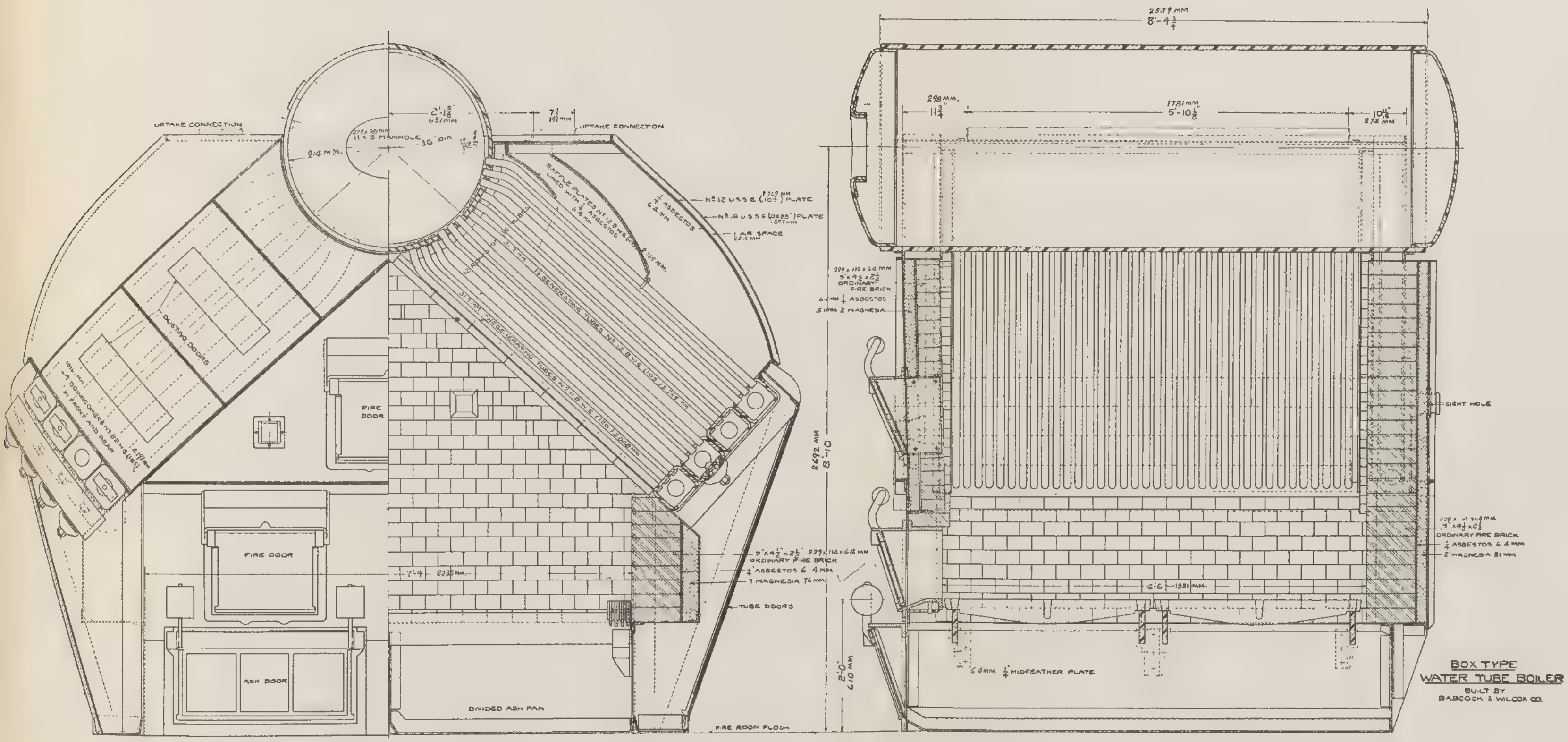
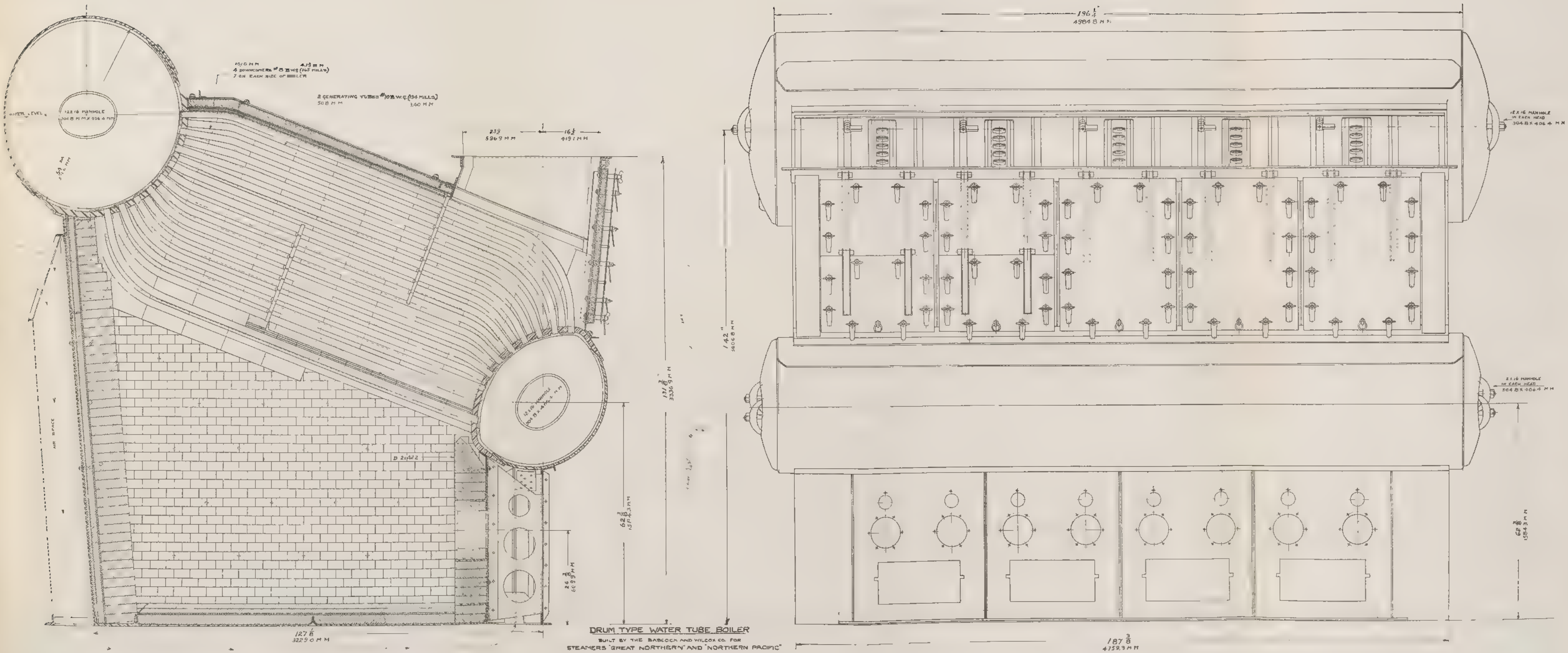

DATA FOR ONE BOILER
STEAM PRESSURE GAUGE
HEATING SURFACE OF TUBES
5375 SQ FT
FURNACE VOLUME
520 CU FT
TOTAL NUMBER OF TUBES
UPPER DRUM
BURNERS FITTED WITH
AIR CONTROLLING REGISTER
AIR DOOR
AIR DOOR
MANHOLE
NORMAND WATER TUBE BOILER
EQUIPPED FOR OIL FUEL
BUILT BY BATH IRON WORKS FOR

Fig. 6.



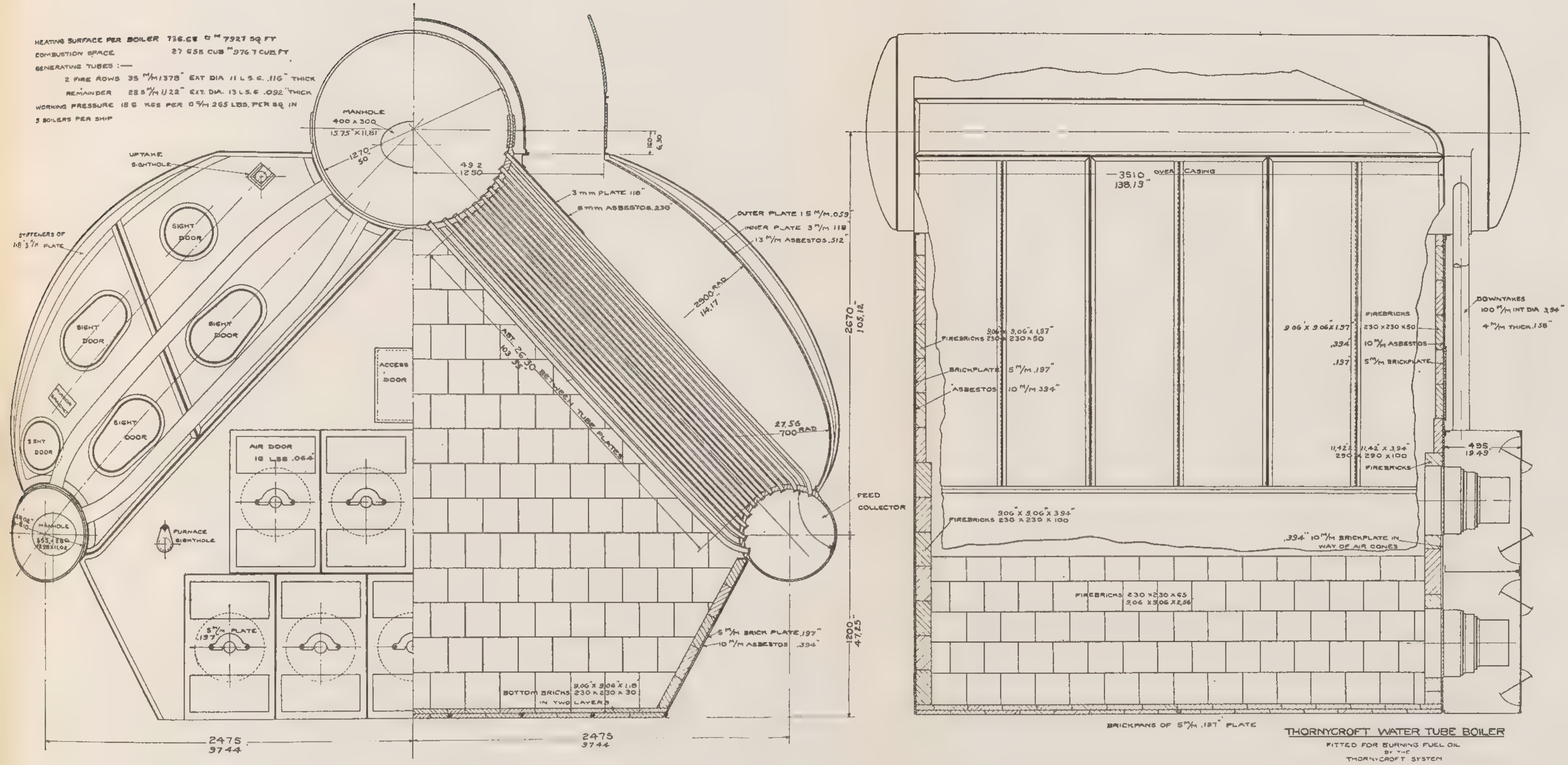
UPTAKE CONNECTION
MANHOLE
36" DIA
DUSTING DOORS
FIRE DOOR
ASH DOOR
DIVIDED ASH PAN
TUBE DOORS
FIRE ROOM FLOOR
AIR SPACE
ORDINARY FIRE BRICK
SIGHT HOLE
MIDFEATHER PLATE
8'-4 3/4"
5'-10 1/8"
8'-10"
2'-0"
BOX TYPE
WATER TUBE BOILER
BUILT BY
BABCOCK & WILCOX CO.

Fig. 7.



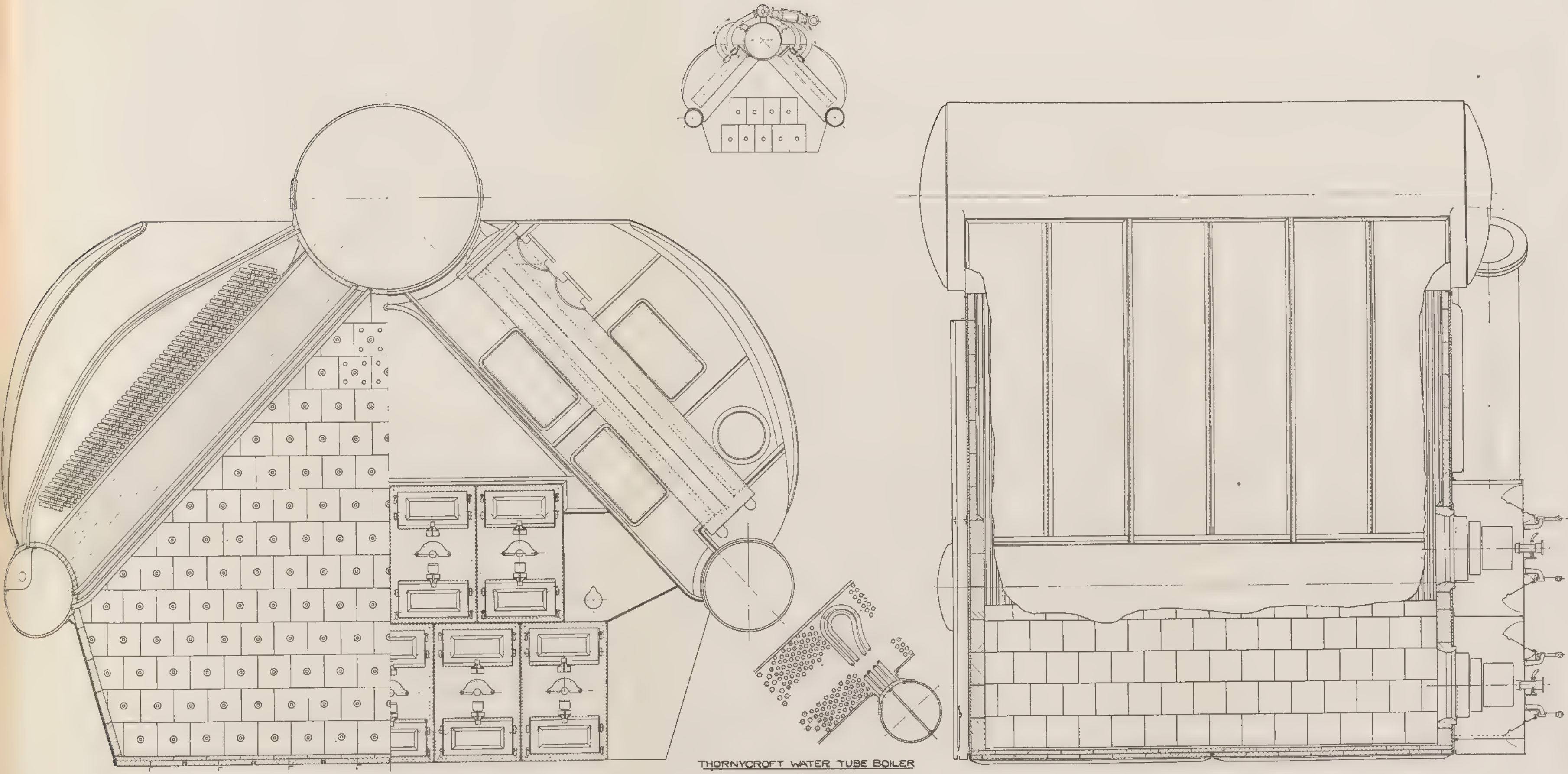
DRUM TYPE WATER TUBE BOILER
BUILT BY THE BABCOCK AND WILCOX CO. FOR
STEAMERS "GREAT NORTHERN" AND "NORTHERN PACIFIC"

Fig. 8.



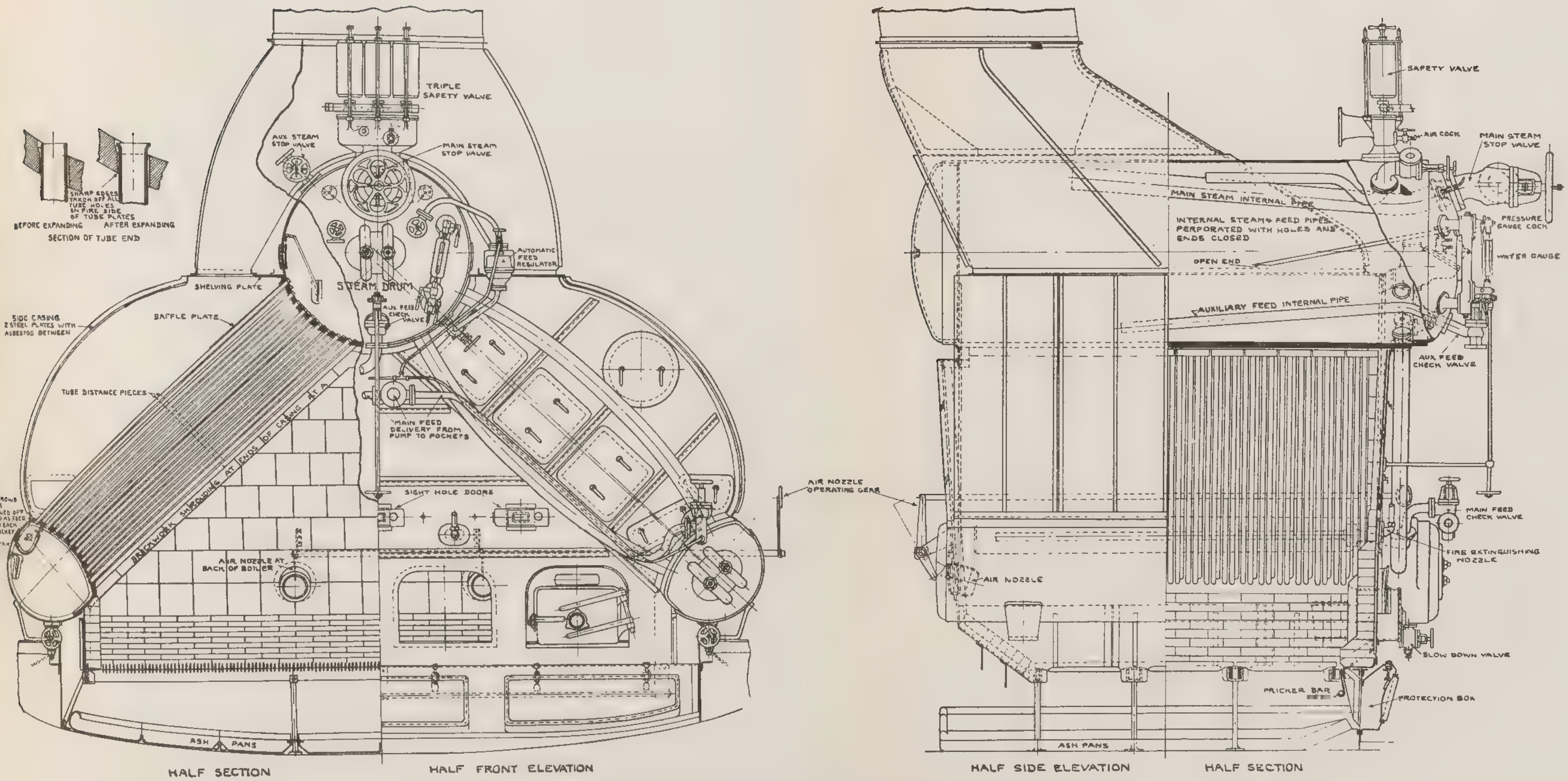
HEATING SURFACE PER BOILER 736.CE ㅁ M 7927 SQ. FT
COMBUSTION SPACE 27 658 CUB M 976.7 CUB. FT
GENERATING TUBES :—
2 FIRE ROWS 35 M/M 1.378" EXT DIA 11 L.S.G. .116" THICK
REMAINDER 28.5 M/M 1.122" EXT. DIA. 13 L.S.G .092" THICK
WORKING PRESSURE 18.6 KGS PER ㅁ C/M 265 LBS. PER SQ. IN
3 BOILERS PER SHIP
UPTAKE SIGHTHOLE
MANHOLE
SIGHT DOOR
ACCESS DOOR
AIR DOOR
FURNACE SIGHTHOLE
FEED COLLECTOR
DOWNTAKES
FIREBRICKS
BRICKPLATE
ASBESTOS
BOTTOM BRICKS
BRICKPANS OF 5 M/M .197" PLATE
2475
97.44
THORNYCROFT WATER TUBE BOILER
FITTED FOR BURNING FUEL OIL
BY THE
THORNYCROFT SYSTEM

Fig. 9.



THORNYCROFT WATER TUBE BOILER
FITTED WITH
FEED HEATER AND SUPERHEATER

Fig. 10.



YARROW PATENT WATER TUBE BOILER
FITTED FOR BURNING COAL

Fig. 11.

particular boiler and the arrangement of the tubes in the steam and water drums so as to permit any particular tube to be removed and replaced through the steam drum without disturbing other tubes in the boiler.

The spare tubes may be carried of the longer lengths and cut to any desired length.

This boiler is now constructed either with D-shaped water drums or circular water drums. Fig. 5 shows the latest type of the White Forster Boiler as built in the United States by the Babcock and Wilcox Company, which embodies the circular water drums.

Owing to the large radius of curvature of the tubes, they are easily cleaned, both internally and externally, and the stresses due to expansion are minimized.

This boiler is capable of developing a very high efficiency and it can also be severely forced without injury.

Normand Boilers.

The Normand boiler has long been considered one of the most efficient and best designed boilers of the express water-tube type. The Normand firm, owing to the early inventive ability and resourcefulness of M. Normand in France, has been particularly successful in the construction of torpedo boats and destroyers fitted with high-power machinery.

Fig. 6 shows a boiler of the Normand type as constructed by the Bath Iron Works for torpedo-boat destroyers. This company has met with singular success in the development of this boiler for U. S. destroyers. The dry weight of the boiler as shown by Fig. 6, complete with all mountings, oil burners and tuyéres, but not including the uptake, amounts to 11.2 pounds per square foot of heating surface (54.6 kgs. per sq. m.) and the weight of water in steaming condition amounts to 2 pounds per square foot of heating surface (9.7 kgs. per sq. m.). The combustion chamber space can be made as large as desired.

Attention is called to the steam dome, provision for baffling the steam before entering the dome, and the arrangement of the tubes so as to baffle the gases and give them a long passage across the heating surface.

The boiler has been forced to extremely high capacities in naval installations in various countries. M. Normand was one

of the first engineers to point out the ill effect of the admittance of feed in such a manner as to interrupt the proper circulation in water-tube boilers and to show the inefficiency resulting from such methods of feeding.

The Box Type of Boiler.

The Box Type of boiler, built by the Babcock and Wilcox Company is shown in Fig. 7. This boiler embodies an ingenious arrangement of steel headers. These headers take the place of the usual water drums in the A type of boiler, and it should be noted that they may be of either the straight box or corrugated form, running either longitudinally or cross-wise of the bank of tubes; this allows great flexibility in regard to size of boiler. These headers are of the regular type incorporated in the Babcock and Wilcox boiler, as shown in Fig. 16. As is apparent from the figures referred to, the boiler is particularly accessible for cleaning and examination of the interior surfaces of the tubes, and if space is allowed in the vessel, any individual tube may be examined and cleaned from either end, and any tube may be renewed without interfering with other tubes.

Drum Type of Boiler.

The Babcock and Wilcox drum type of boiler is shown in Fig. 8 which represents these boilers as recently installed in the Steamers "Great Northern" and "Northern Pacific". The boiler is fired from the water-drum side, which gives an efficient furnace arrangement and is well adapted for either coal or oil burning. The baffling is across the tubes and is of the well-known and efficient Babcock and Wilcox type. The boilers illustrated were fitted with Schütte and Koerting fuel-oil burners.

Thornycroft Boilers.

The latest form of Thornycroft boiler is constructed with tubes which are straight excepting at the lower ends where they enter the cylindrical water drums. The curvatures of the tubes are limited to only two or three radii, which simplifies the spares. This design enables each tube to be examined internally by placing a light at the lower end; it also allows flexibility for expansion. The tubes are easily cleaned internally and are so disposed in cross section as to be accessible for external sweeping. The cylindrical water pockets are the most economical in

weight and cost of construction. It is feasible to make the water pockets of welded or solid drawn construction, which obviates the dangers of leaky seams in case cold feed is admitted to the bottom drums as indicated in Figs. 9 and 10. The down-take tubes are designed to facilitate the minimum fluctuations in water level. The boiler is well adapted for the installation of superheaters.

The combustion chamber space can be made as large as desired, and usually for oil-burning boilers is about 0.09 to 0.12 cubic feet per square foot (0.0274 to 0.0366 cu. m. per sq. m.) of heating surface.

Fig. 9 shows the Thornycroft latest design of boiler. When superheaters are installed they are arranged between the boiler casing and the generator tubes as shown in Fig. 10.

Messrs. Thornycroft and Company, Limited, have supplied their system of oil-fuel apparatus for numerous naval and mercantile vessels throughout Europe and America. Such installations, which have been made or are now being made, amount to over 2,000,000 horse power.

Sir John I. Thornycroft is a particularly noted contributor to the original investigations and developments which are resulting in the modern, efficient water-tube boiler.

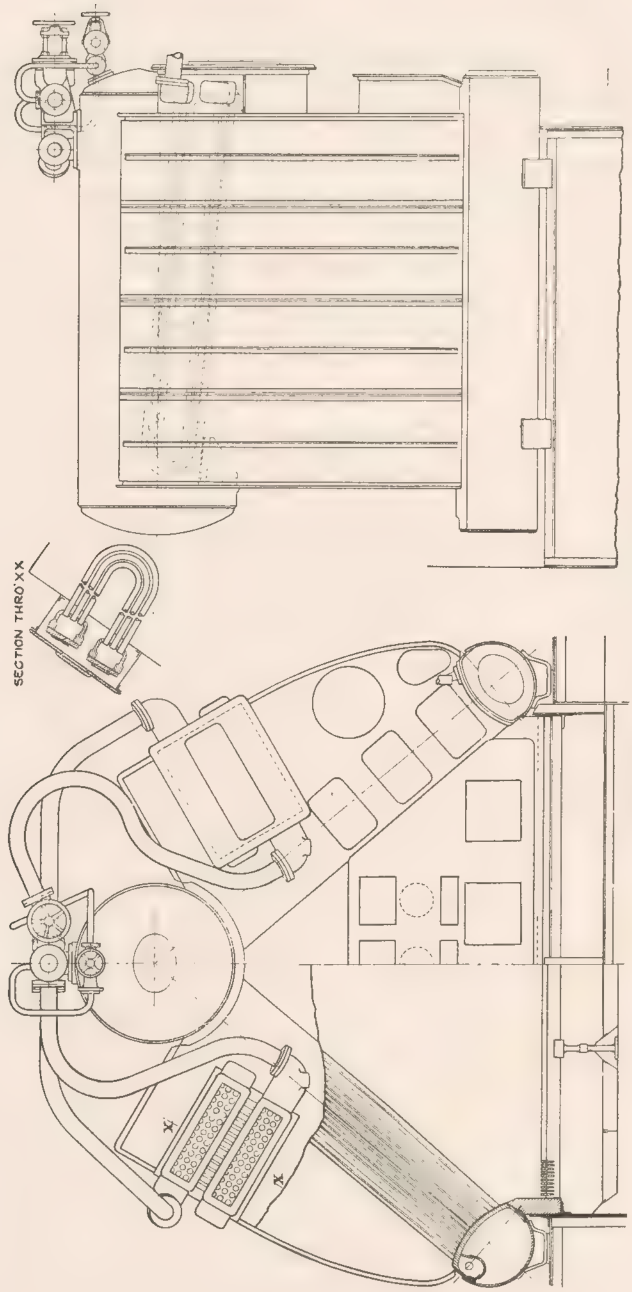
Yarrow Boilers.

The Yarrow boiler has been largely adopted by the British Admiralty and by other admiralties for destroyers, intermediate vessels and the largest types of battleships and battle cruisers. This was one of the boilers selected by the British Admiralty after an exhaustive report by its committee in 1902.

These boilers are sometimes fitted of the double-end type and arranged for oil burning in conjunction with coal burning, which provides a large overload factor quickly available.

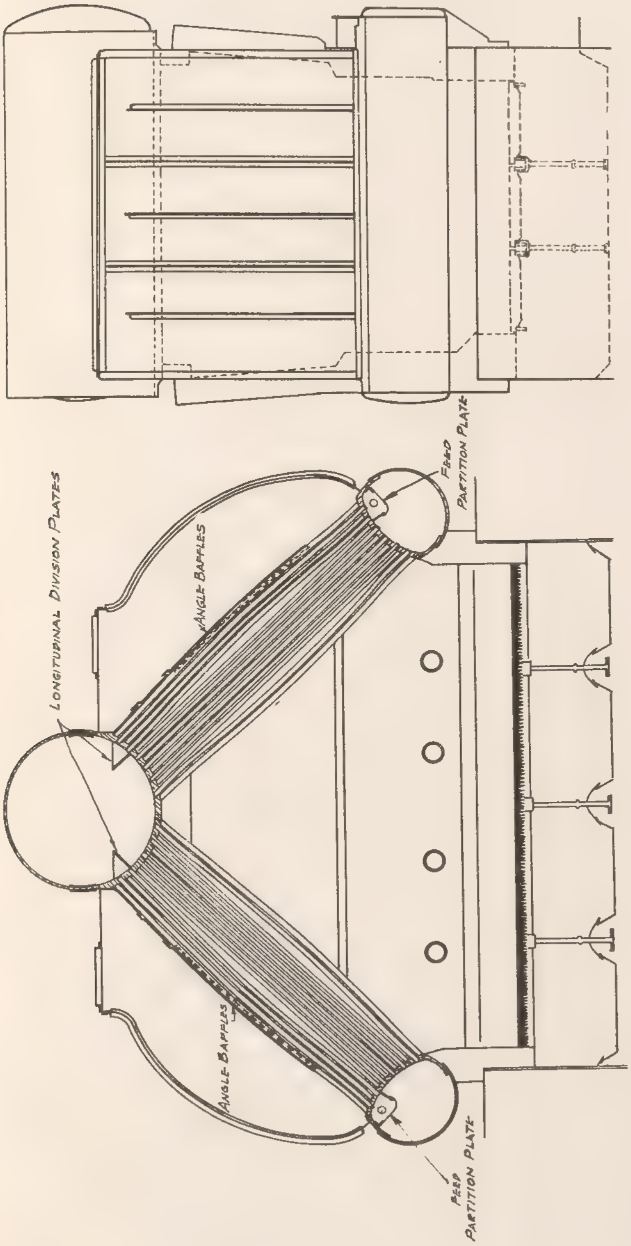
The general construction of the Yarrow boiler is well known Fig. 11 represents the boiler fitted without superheaters; Fig. 12 represents the boiler fitted with superheaters; Fig. 13 shows the boiler as now usually fitted with angle-iron baffles and longitudinal feed division plates, as recommended by Messrs. Yarrow.

The high class of work done by the Yarrow Company, both in design and construction, and the large number of experi-



YARROW WATER TUBE BOILER
WITH STEAM SUPERHEATER
FOR
H.M.S. "YARMOUTH"

Fig. 12.



YARROW BOILER SHOWING ANGLE BAFFLES AND LONGITUDINAL DIVISION PLATES.

Fig. 13.

ments which have been conducted in studying the principles of correct boiler construction, theory of operation and efficient working have placed the Yarrow boiler in an enviable position as regards efficiency, endurance, and other important particulars. One of the cuts shows outside down-comers, but Mr. Harold Yarrow states that these have now been abandoned as being unnecessary.

Messrs. Yarrow state that the forty-two boilers built for the Chilean Battleships "Almirante Latorre" and "Almirante Cochrane", are the last battleship boilers which they have constructed without superheaters.

These boilers are arranged with the Yarrow special feed-heating device which is now being fitted in all of the boilers built by Messrs. Yarrow for destroyers, battleships, cruisers and other war vessels. As indicated in Fig. 13,* the cold feed enters the lower drums and passes up the outside rows of tubes in each water pocket. In the case of the Chilean battleships the four outside rows of tubes were used for the feed to ascend. A longitudinal division plate is fitted in the steam drum to deflect this feed as it enters the drum and prevent it from short circuiting back to the water pockets, as it has been found that such short circuiting has a tendency to cause excessive stresses in the water pockets and seams. The boiler is fitted with angle-iron baffles as indicated in Fig. 13. These consist of ordinary angle irons laid in the spaces between certain of the outside rows of tubes in order to more uniformly distribute the gases and it has been found that these considerably increase the efficiency of the boiler.

Two trials, each of 12 hours' duration, were run on one of the Chilean boilers when burning fuel oil only. One trial was made with the feed entering both water pockets and ascending the outside tubes, on which trial, with oil having a calorific value of 19,000 B.t.u's. per pound (10,550 cal. per kg.) and running at low power, 16.81 pounds (kg.) of water from and at 212° F. (100° C.) were evaporated per pound (kg.) of oil; during a similar trial with the feed water entering the steam drum the corresponding evaporation fell to 15.83 pounds (kg.).

* "The Yarrow Boiler", Engineering, Vol. 95, page 681 (1913).

The uptake temperature in the first trial was 312° F. (155° C.) and in the latter trial this temperature rose to 423° F. (217° C.). These trials indicate the advantage obtained by this system of feeding.* An interesting discussion of the heat analysis in connection with these trials has been contributed by Mr. Donald W. Rennie.†

The Yarrow boiler has been most extensively adopted in a large number of navies, the total installations since 1905 amounting to well over 4,000,000 horse power.

Messrs. Yarrow feel that the future development of marine boilers for naval vessels will be largely along the lines of increasing the rapidity of circulation and that this will require tubes placed at a considerable angle to the horizontal. Liberal combustion space for the burning of oil fuel will also be required, since all boilers of this class should be capable of being forced to the highest extent without detriment whenever emergency conditions require.

Attention is called to the very high rates of combustion which may be obtained in the Yarrow boiler.*

The Yarrow boiler is to be noted for the following points, emphasized by Messrs. Yarrow & Co.

(1) The simplicity of design embodying straight tubes, excepting those adjacent to the furnace, which are slightly bent for taking up expansion. This facilitates inspection and cleaning of both fire side and water side of the tubes.

(2) The rapid circulation due to the inclination of the tubes and regardless of the rolling of the ship in a sea way, which is especially important with high rates of evaporation now required in war ships. As is well known, intense circulation increases the efficiency of the boiler, and, in addition, it tends to clear the tubes of dirt or sediment and therefore facilitates operation with less frequent cleaning.

(3) Accessibility, freedom from numerous joints, together with the embodiment of the best designs, materials and workmanship, reduce the time required for repairs to a minimum. These qualities of the boiler also facilitate rapidity of raising

* Harold E. Yarrow, Institution of Naval Architects, March (1912).

† "The Heat Analysis of an Oil-fired Water-tube Boiler", Donald W. Rennie, The Engineer, Vol. XCVII (1914).

steam, which has been especially emphasized during the last few months.

Babcock and Wilcox Marine Boilers.

This boiler has been installed in both small and large powers in a great number and variety of vessels. It is one of the boilers selected by the British Admiralty after the report by its boiler committee in 1902. The company have large shops in the United States and Scotland equipped with the best special machines and tools, and they also have works in France and Germany.

The dry weight of the boiler when built for 250 to 295 pounds working pressure (17 to 20 atmos.) is about 20 pounds per sq. ft. of heating surface (98 kgs. per sq. m.), as compared with 40 to 50 pounds per sq. ft. (195 to 244 kgs. per sq. m.) for Scotch boilers for 180 pounds pressure (12.2 atmos.). The water in such Scotch boilers varies from 17 to 20 pounds per sq. ft. of heating surface (83 to 98 kgs. per sq. m.). In large Babcock and Wilcox boilers arranged for oil firing and fitted with 2 in. (51 mm.) tubes, No. 10 B.W.G., in thickness, the dry weight is below 16 pounds per sq. ft. of heating surface (78 kgs. per sq. m.).

The water in the boiler amounts to 3 to 5 pounds per sq. ft. (15 to 24 kgs. per sq. m.) of heating surface. The water in the boiler shown in Fig. 14 weighs 2.9 pounds per sq. ft. (14.1 kgs. per sq. m.). There is no useless water in the boiler and the circulation is active.

The American coal-burning boiler is constructed with the tubes placed at 15° inclination to the horizontal and with forged-steel side water pockets below the tubes, which form excellent furnace sides for coal firing and efficient heating surface. In the English type of this boiler for coal burning the grates of adjacent boilers sometimes extend to a common division wall between the boilers, with cleaning space provided at the side doors above this division wall; this permits a considerable increase in the grate area, which is an advantage for long high-powered runs where cleaning fires is an important condition.

The American type of boiler, built for oil fuel, is also fitted with side brickwork and without side water boxes below the

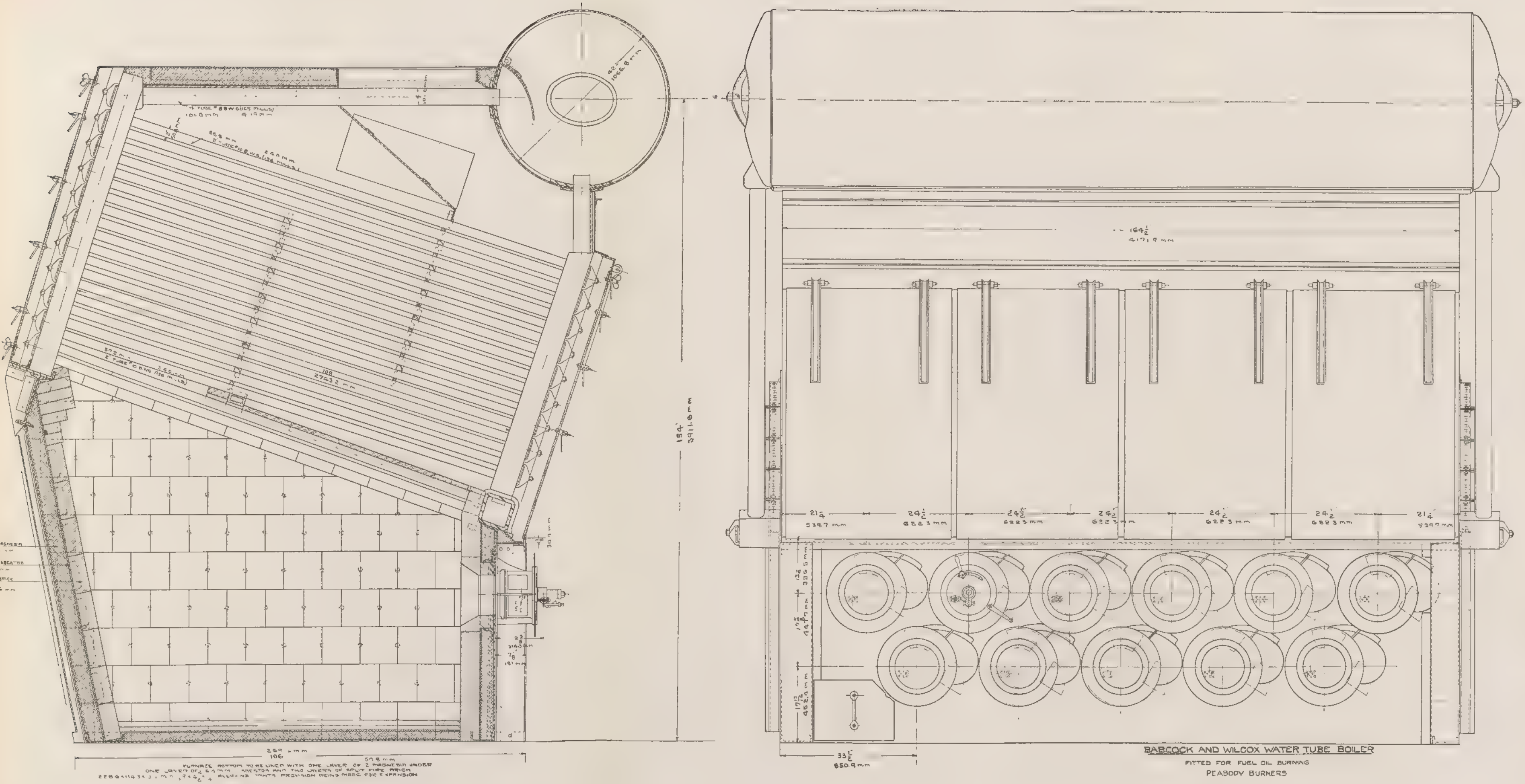

BABCOCK AND WILCOX WATER TUBE BOILER
FITTED FOR FUEL OIL BURNING
PEABODY BURNERS

Fig. 14.

tubes. The lower rows of tubes immediately above the furnace for oil burning are usually inclined 18° from the horizontal while the tubes above these are inclined 15°. This is shown in Fig. 14.

Reference to Figs. 15, 16, 17 and 21 indicates the accessibility for cleaning and repairs on both the water and fire sides of the

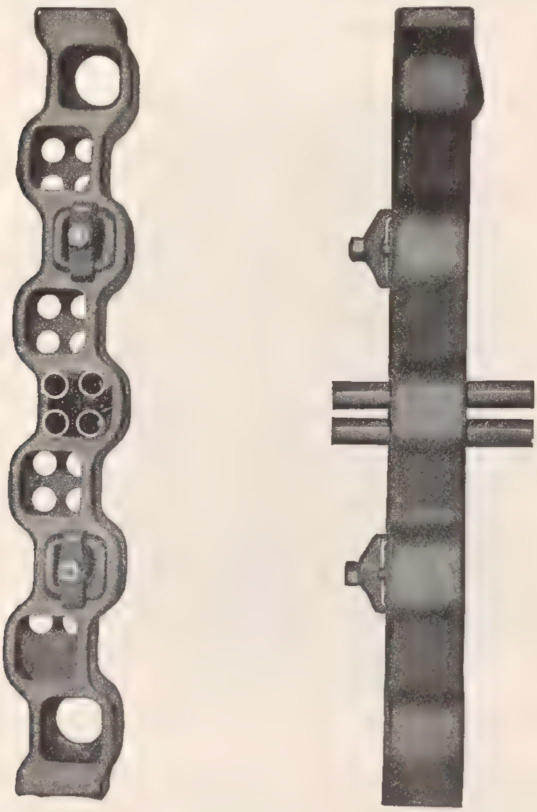


Fig. 15. B. & W. Boiler. Forged Steel Header. Handhole Covering Group of Four 2-inch Tubes.

tubes. The fire side of the boiler can be cleaned efficiently while under steam, as the cleaning doors are arranged on the side. The tubes being straight and accessible from either end are easily inspected and renewed. The Southern Pacific Company find that in their Steamer "Creole" they can blow down a boiler, renew a tube and again get up steam in about two hours.

Admiral Melville's requirement that no cast metal subjected to pressure should be employed in a water-tube boiler has been fully met. The tools for working and forming the pressure parts of these boilers are such as to preserve the best qualities of the materials used, so that a high factor of safety is maintained.

Repeated authentic tests show that steam can be raised from water of 100° F. (38° C.) to a pressure of 200 pounds per sq in. (13.6 atmos.) within 15 minutes, without injuring the boiler.

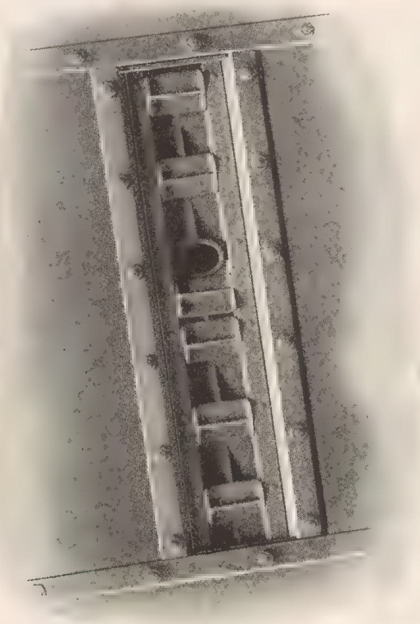


Fig. 16. B. & W. Boiler. Dusting Panel—Patented.

The efficiency of the boiler with oil fuel rises as high as 80% under test conditions; with coal fuel the corresponding efficiency is about 75%. These efficiencies, of course, are with low rates of combustion, but the efficiency is well maintained with high rates of firing, as will be noted by reference to the tests of the "Arkansas" and "Wyoming" boilers both with coal and oil fuel.* The boiler has been tested to extremely high rates of

* "Test of Babcock and Wilcox Boilers for U. S. Battleships 'Wyoming' and 'Arkansas'", Journal of A. S. N. E., Nov. 1910, Vol. XXII; May 1911, Vol. XXIII.

combustion, corresponding to 70 pounds of coal per sq. ft. of grate surface per hour (342 kgs. per sq. m.), and such tests have been run without injury.

The space occupied by the Babcock and Wilcox boiler is small as compared with Scotch boilers and satisfactory as compared with other water-tube boilers.

The parts of the boiler are made interchangeable and although many are special, still the items subject to the greatest

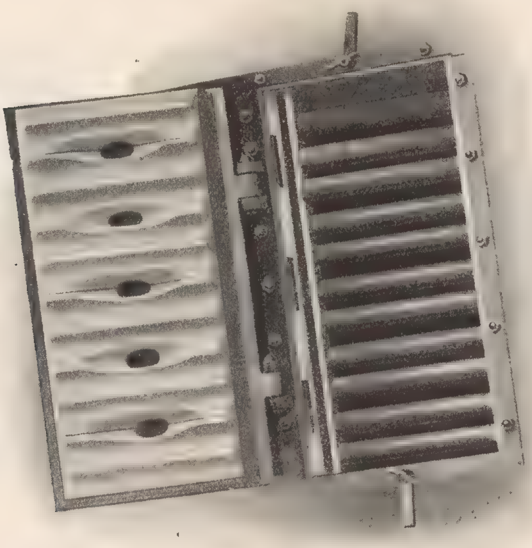


Fig. 17. B. & W. Boiler. Cleaning Panel—Patented.

deterioration are of commercial sizes which can be readily procured.

The form of furnace is well adapted to complete combustion before the gases enter the tubes, the vertical baffles direct the gases three times, at right angles, across the tubes, and since the tubes are staggered, as will be seen by reference to Fig. 15 showing the header, the gases are brought into intimate contact with the heating surface.

The circulation in the boiler is rapid and efficient and at the same time the steam surface is liberal and the quality of the

steam is remarkably dry. Fig. 18 shows the drum arrangement and circulation. The feed enters the large drum and descends through the nipples and front headers, from which it passes into the tubes; mixed steam and water fill the back headers and pass through the return tubes entering the steam and water drum back of the baffle plate; the steam passes around the ends of the baffle into the steam space. Tests of the "Wyoming" boiler showed that when evaporating 14¾ pounds of water per sq. ft. of heating surface (72 kgs. per sq. m.), from and at 212° F. (100° C.) the steam was 99.57 percent dry.

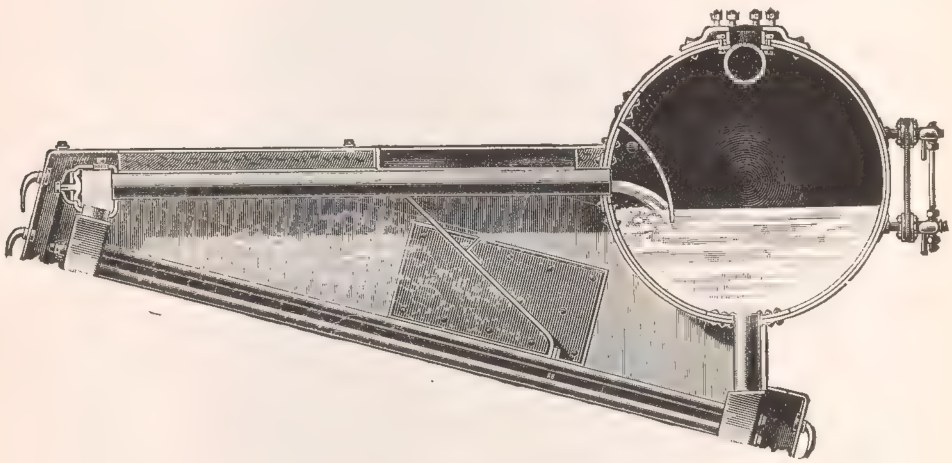


Fig. 18. B. & W. Boiler. Showing Drum Arrangement and Circulation.

The boiler is of rugged construction and experience shows that it can be efficiently operated by the regular firemen found in service. The furnaces being all of one height is a great advantage and much favored by the firemen, as it is easier to work the fires in such furnaces than to work the high side fires of four-furnace Scotch boilers.

In regard to durability, it may be said that these boilers have been in operation in several steamships for periods of from eight to fourteen years with only minor expenses for repairs and are still in good condition. To cite an example, the Steamship "Creole" has ten Babcock and Wilcox boilers installed in 1907 containing 28,500 sq. ft. of heating surface (2650 sq. m.), 4350 sq. ft. (404 sq. m.) of superheating surface and 783 sq. ft. (72.7

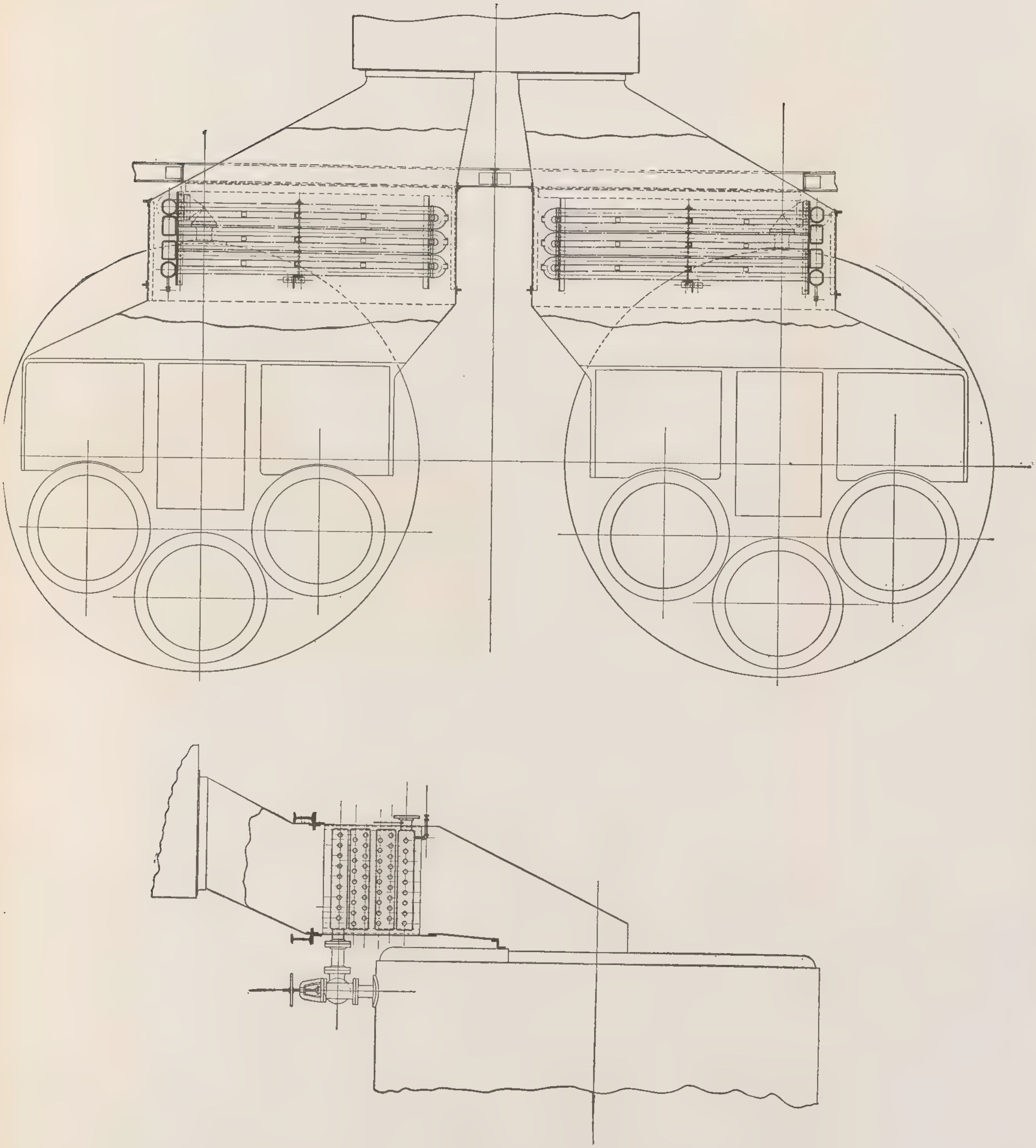


Fig. 19. Arrangement of Foster Superheaters in Uptakes of Steamer "Lyman Stewart."

sq. m.) of grate surface. The trip is usually made operating only seven of the boilers. The pressure parts of the boilers, with the exception of a few superheater tubes, do not show any appreciable deterioration. This condition is attributed to the fact that the boiler water has been kept fresh.

Experience shows that these boilers can be kept clean as easily as Scotch boilers. Boiler cleaning in the "Creole" is all performed by the crew. The owners have sometimes employed outside labor to clean the internal parts of Scotch boilers in other vessels of their line.

The expense for upkeep of these boilers has been very much less than the corresponding expense of upkeep of Scotch boilers in sister vessels. The deterioration of the boilers in use is less than that of the boilers which are not in use. The casings are still in good condition and less expense has been entailed in maintaining these casings than has been expended in repairs to the ordinary galvanized-iron covering over the lagging used on the Scotch boilers of sister vessels.

Much along the same line might be said for this boiler in naval vessels, but in such work the water-tube boiler is a necessity and the grade of men to operate and care for them is higher than in merchant vessels.

SUPERHEATED STEAM.

The saving due to superheat has long been recognized, but marine engineers have been slow to take advantage of this saving owing to the fear of trouble in the lubrication of the cylinders, the danger of oil in the boilers, and to the effect of superheated steam on the cylinders, valves, pipes and fittings. Difficulty in connection with pipes, fittings and valves has been mostly overcome and now the use of superheated steam in marine work is rapidly increasing; the adoption of turbines with reduction devices will minimize the danger in connection with superheat used in large direct connected turbines.

Many installations have demonstrated a great economy by the use of superheated steam. From 8% to 15% saving in fuel consumption frequently appears possible. Several forms of marine superheaters are being installed, principally of the U-tube type. The best known types are the Foster, Babcock and

Wilcox, Niclausse, Schmidt, Yarrow and the Thornycroft superheaters. The independently-fired superheater is not much used in marine work. Superheaters formed of straight tubes rigidly held at each end appear to be difficult to keep tight.

The Foster Superheater is arranged in the uptakes, and therefore is not adapted for high degrees of superheat, but with ordinary boiler pressures of about 180 pounds per sq. in. (12.2 atmos.), it is feasible to obtain from 60° to 65° F. superheat (15° to 18° C.). This gives the advantage of thoroughly dry steam, of temperatures which are not too high for use in the main engines and auxiliaries without the use of special lubrication, and also facilitates the manoeuvering and starting operations.

This system is made up of a system of coils of U-tubes, and the steam is conducted in parallel, the run being about 50 feet (15.2 m.). The steam is passed back and forth six or more times at a velocity of about 5000 feet per minute (1525 m.). The tubes are usually two inches diameter, of cold-drawn steel bent to U-shape and connected through forged steel headers. The exterior of the tubes is covered with cast iron casings accurately bored and tightly shrunk on.

Fig. 19 shows the arrangement of the Foster superheater in the uptakes of the Steamer "Lyman Stewart", which is plying on the Pacific Coast.

Fig. 20 shows the method of connecting the U-tubes to the headers and the cast iron casing covering the tubes. This cut also indicates the interior tubes which are placed within the superheating tubes, thus providing a narrow annular space for the passage of the steam, which increases the heating efficiency.

The Thornycroft Superheater is shown in Fig. 10 and consists of the U-tubes placed between the main body of generating tubes and the casing.

The Babcock and Wilcox Superheater is arranged in the boiler, as indicated in Fig. 21. Due to the location of the superheater at the end of the first pass of the gases through the boiler tubes, arrangement of baffles, and the practicability of providing more or less heating surface, a considerable range of superheat may be provided.

These superheaters in service have proven durable and satis-

factory, both in merchant work and in naval vessels, with pressures as high as 300 lbs. (20.4 atmos.).

The superheaters in connection with the Babcock & Wilcox boilers in the steamer "Creole" which have been in service since 1907 are in good condition, with the exception that some of the superheater tubes show minor corrosion at the ends extending into the headers. In such a case the tube is easily cut off just back of the header and reinserted and expanded with very slight loss of superheating surface.

Yarrow Superheater. One form of Yarrow superheater is indicated in Fig. 12. Other proposed forms have been illustrated.*

Mr. Yarrow informs the author that all of the war ships they are now building are being fitted with superheaters and there

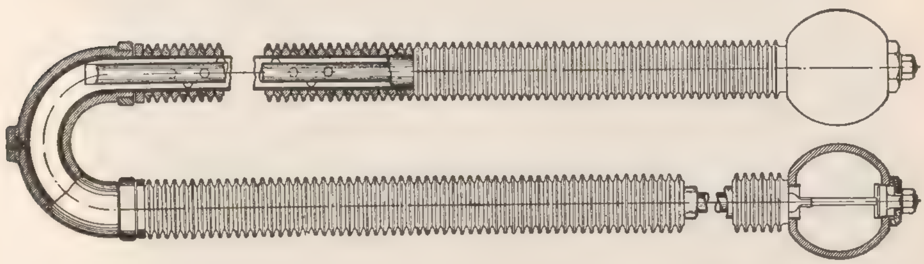


Fig. 20. Cross Sectional View of Return Bend Element and Connecting Headers Used in the Construction of Foster Superheaters.

is no doubt that there is advantage in both high and low speeds by their adoption.

The Robinson Type of Superheater was illustrated in April. 1915, in the Shipbuilding and Shipping Record.

The Robinson superheater is particularly applicable to Scotch boilers. It is of the principle of the small U-tube inserted in the regular heating tubes of the boiler. A unique arrangement of inserting the tubes in the headers is employed.

The Schmidt Superheater has been extensively used in several countries for locomotive service and is also probably the most widely adopted superheater for merchant-marine work. The

*"Results of Experiments with a Water Tube Boiler with Special Reference to Superheating", Harold E. Yarrow, Institution of Naval Architects, 1912.

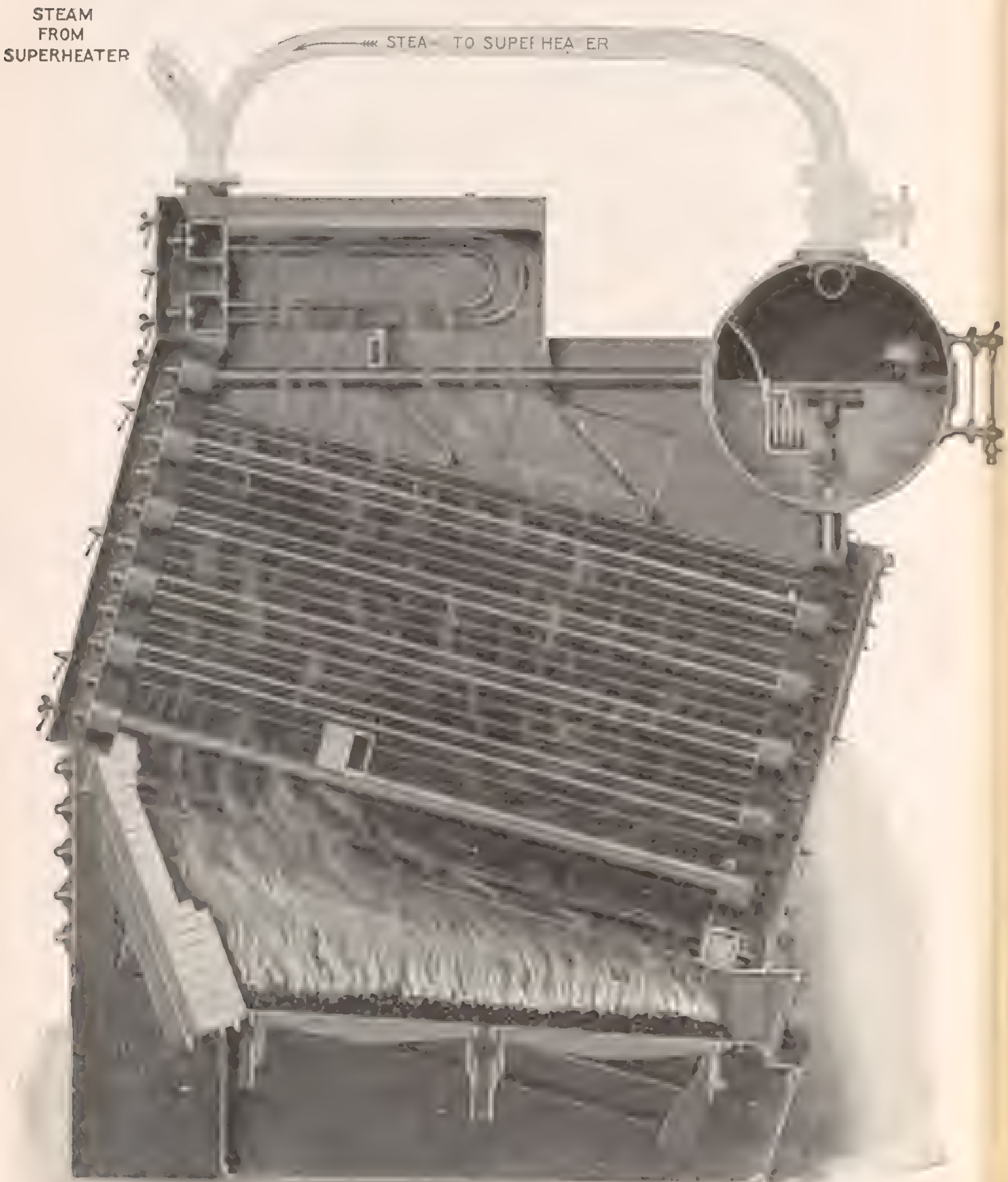


Fig. 21. Babcock & Wilcox Superheater.

principle of this superheater is shown in Figs. 22 and 23. It is largely used in connection with Scotch boilers, and, as is well known, consists of the small U-tubes inserted in the regular tubes of the boiler.

Over 1200 steamers, which total over 1,500,000 horse power, are now fitted with these superheaters, either as original installations, or as changes from saturated steam jobs. One advantage of this type is that it can be readily installed in saturated steam Scotch boilers with few changes in piping, it being necessary of course to modify the engine valves to adapt them for high temperatures. The temperatures used in marine boilers with this superheater are from 575° F. to 625° F. (302° to 329° C.).

Sir Charles A. Parsons* states in connection with superheaters of the Schmidt type that he considers: "First and most important the placing of the superheater tubes in close proximity to a boiler surface, as when a single convolution of a superheater tube lies within the fire tube of a Scotch boiler, the great advantage being that the superheater tube is saved from burning by the rapidity of its radiation to the contiguous surface; the second important factor is that of high steam velocity so as to scour out and keep the tubes clean".

Calibrated pyrometers should be installed in the engine room, and saturated steam connections should be fitted to the superheated steam pipes for regulating the amount of superheat. Such an arrangement is shown in Fig. 24.

The U-tubes are connected to the headers of the Schmidt superheater by an ingenious clamp which enables any tube to be quickly removed. Very little difficulty has been found with these connections.

The cleaning of the boiler tubes when fitted with this type of superheater is a point which some engineers may consider serious, but as this superheater is usually installed in boilers fitted with forced draft and as soot blowers of the Diamond type which may be operated from the backs of the boilers, are generally fitted in the combustion chambers, the tubes are swept each watch with very little work and kept in efficient condition.

*North East Coast Institution of Engineers and Shipbuilders, Volume XXX, Transaction, 1913-1914.

The Diamond blower as fitted in connection with this superheater is illustrated in Figs. 25 and 26. The nozzle of the blower, as it is operated, travels out from its casing which pro-

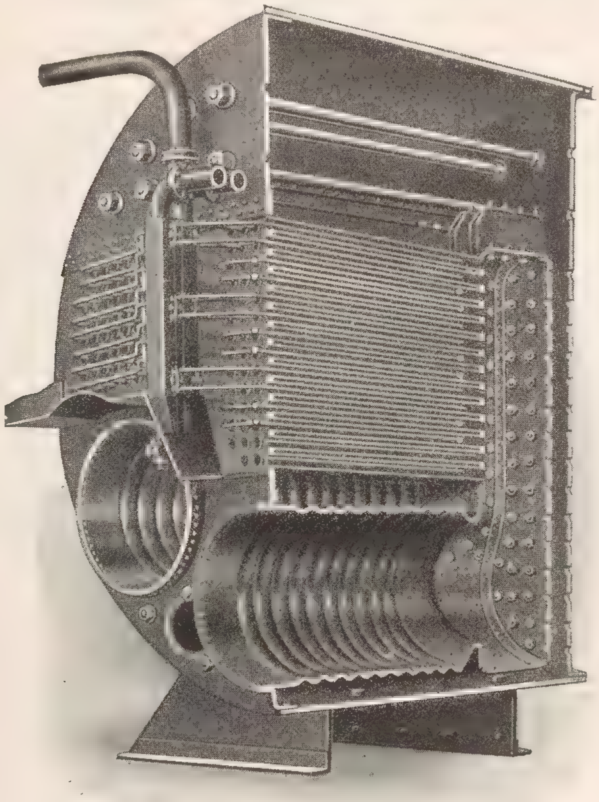


Fig. 22. Sectional View of Internally Fired Marine Boiler, Showing Location of Superheater Elements in Fire Tubes.

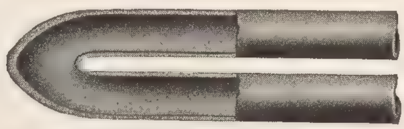


Fig. 23. Sectional View of Continuous Return Bend Used in Schmidt Fire Tube Superheater Elements.

tects it from the heat. As it travels out and in, the angle of the nozzle changes so as to direct the steam or air, which is used for blowing the soot, in an increasing and decreasing spiral which reaches all the tubes.

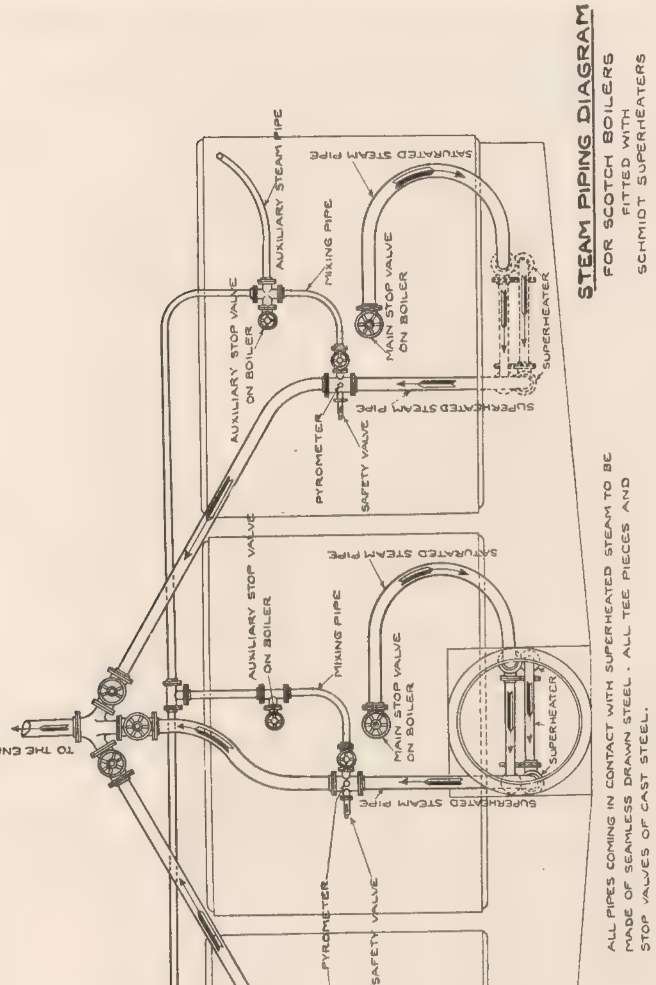

STEAM PIPING DIAGRAM
FOR SCOTCH BOILERS
FITTED WITH
SCHMIDT SUPERHEATERS
ALL PIPES COMING IN CONTACT WITH SUPERHEATED STEAM TO BE
MADE OF SEAMLESS DRAWN STEEL . ALL TEE PIECES AND
STOP VALVES OF CAST STEEL.
TO THE ENGINE
SATURATED STEAM PIPE
AUXILIARY STEAM PIPE
MIXING PIPE
AUXILIARY STOP VALVE
ON BOILER
MAIN STOP VALVE
ON BOILER
SUPERHEATER
SUPERHEATED STEAM PIPE
PYROMETER
SAFETY VALVE
SATURATED STEAM PIPE
AUXILIARY STOP VALVE
ON BOILER
MIXING PIPE
MAIN STOP VALVE
ON BOILER
SUPERHEATER
SUPERHEATED STEAM PIPE
PYROMETER
SAFETY VALVE
AUXILIARY STOP VALVE
ON BOILER
MIXING PIPE
MAIN STOP VALVE
ON THE BOILER
SUPERHEATED STEAM
SUPERHEATER
SATURATED STEAM PIPE

Fig. 24.

The boiler may also be cleaned by blowing the tubes from the front if preferred.

When using superheated steam of high temperatures, it is necessary to provide some lubrication for the pistons and valves in the main engine. This has been the source of much discussion. The fear of using oil in the steam for marine work has probably delayed the installation of superheaters in steamers, but present experience indicates that with the proper use of high-heat mineral oil, and with efficient oil extractors, there need be no trouble from oil in the boilers.

There are several types of oil filters which may be used for this service, some of which consist of a simple form of a cartridge in which the water enters in the middle and is forced through an annular space filled with cocoa fibre; this filter may be fitted both on the suction side and the discharge side of the pump. Some engineers provide for large filter tanks and slow movement of the water to enable any oil to be collected.

ARRANGEMENT OF FIRE ROOM.

In large passenger vessels, the arrangement of the boilers and fire-rooms to provide for efficient operation and the least interference and encroachment upon passenger spaces are points for special study by engineers and naval architects. The arrangements in the Hamburg-American Line steamers "Vaterland", "Bismarck", and others, in which the uptakes are carried to the stacks from the outboard sides of the fire-rooms, thus permitting through fore and aft passages in the saloons and public rooms, are worthy of mention.

The arrangement of screen bulkheads in the fire-rooms providing large down-take spaces for fresh air and enclosed spaces over the boilers, extending to the fronts of the uptakes for carrying away the heated air, provides good stokehold ventilation for ordinary vessels and improves the fire-room conditions as frequently observed.

The demand in naval work to reduce the number of stacks and to armor the uptakes above the protective deck, in order to protect the boiler installation, requires long uptakes, and hence the importance is seen of maintaining the lowest temperatures in the uptakes under forced conditions.

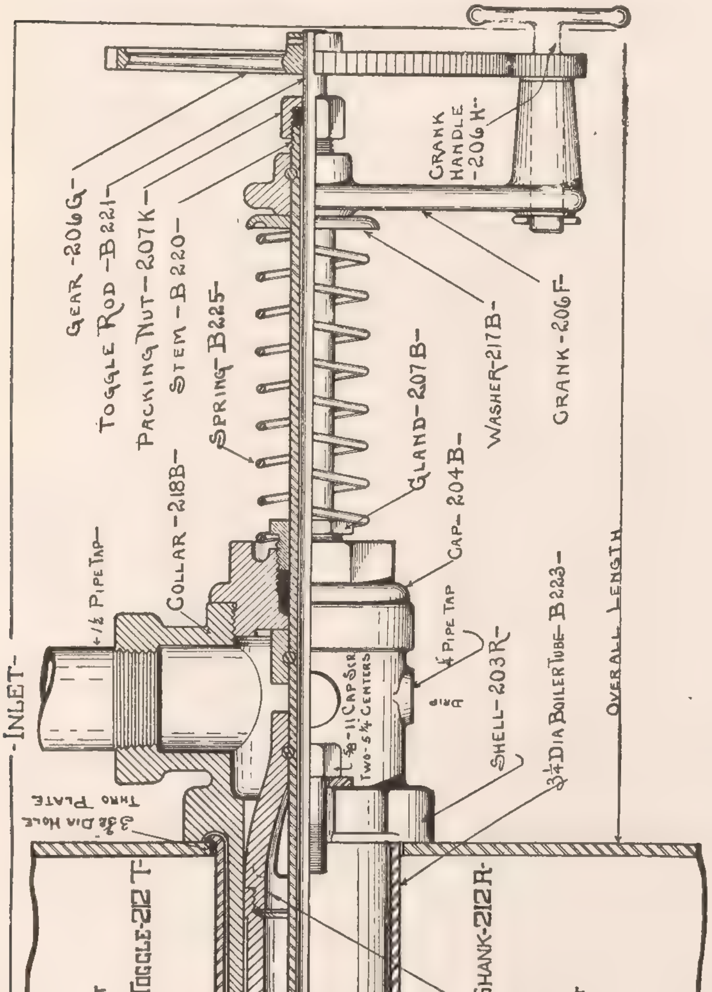


Fig. 25. Diamond Soot Blower.

The escapes from air-tight fire-rooms should start from air-locks at the bottom of the fire-room to minimize the danger in case of accidents which might fill the boiler room with steam.

The arrangement of side bunkers in large merchant vessels provides for a greater coaling length, which materially facilitates coaling in port.

BOILER ROOM PIPING, VALVES, ETC.

The steam piping from the boilers should be arranged with drainage trapped or led back to the boilers and with sufficient freedom for expansion. There is a tendency to abandon copper material for steel, and with high temperatures and pressures the piping should be of seamless steel.

Automatic self-closing valves are sometimes installed as boiler stop valves to prevent, in the case of the bursting of a boiler tube, the steam and water from other boilers blowing through the disabled boiler, but such devices are not very popular. Engineers usually prefer to have the valves positively operated from place and from deck or from an adjacent compartment.

Blow valves are now being made of the seatless hollow-piston type, with clear opening to give the least resistance and without projections upon which sediment may accumulate.

Safety-valve regulations for merchant work are prescribed by the various Governments and classification societies; these do not present the uniformity desirable. If rules could be adopted by the principal maritime countries prescribing the same essential characteristics for such valves, it would be of much advantage. Corresponding inconsistencies exist in the rules governing boiler scantlings.

Fig. 27 indicates how, for a special case of a Scotch boiler of given diameter, the allowed working pressure, or the thickness of the shell, varies under different classification societies and Government regulations.

The same variations apply to the steam and water drums of water-tube boilers.

BOILER ROOM COMMUNICATION.

This subject is becoming more important owing to the increased size of boiler installations, the tendency to greater sub-

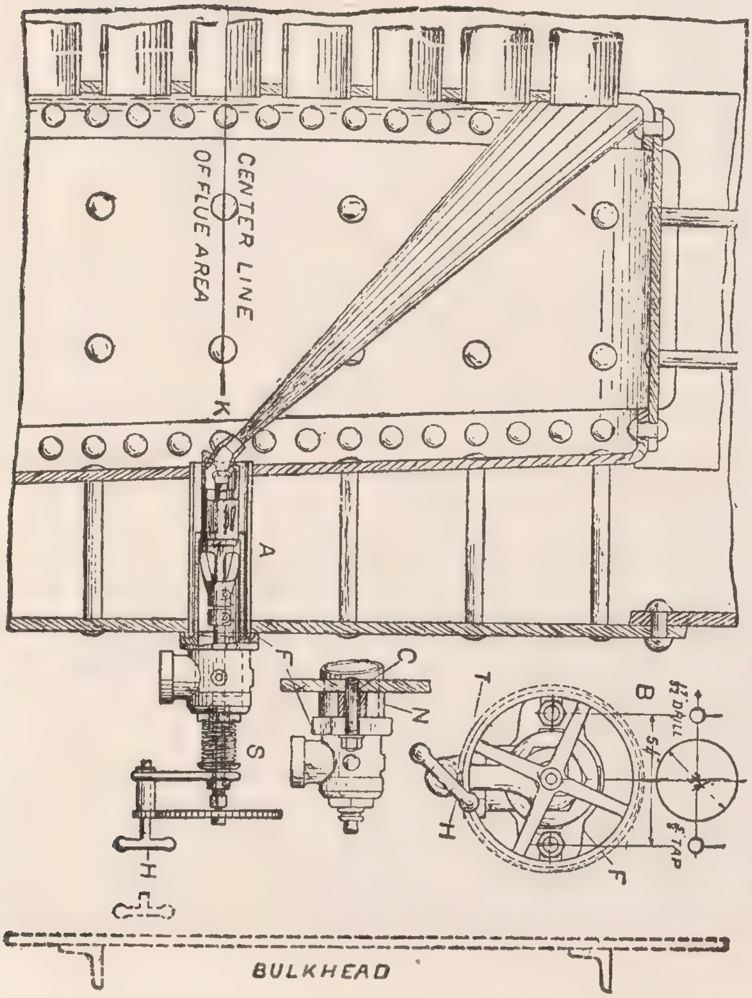


Fig. 26. Arrangement of Diamond Soot Blower in Connection with Schmidt Superheaters.

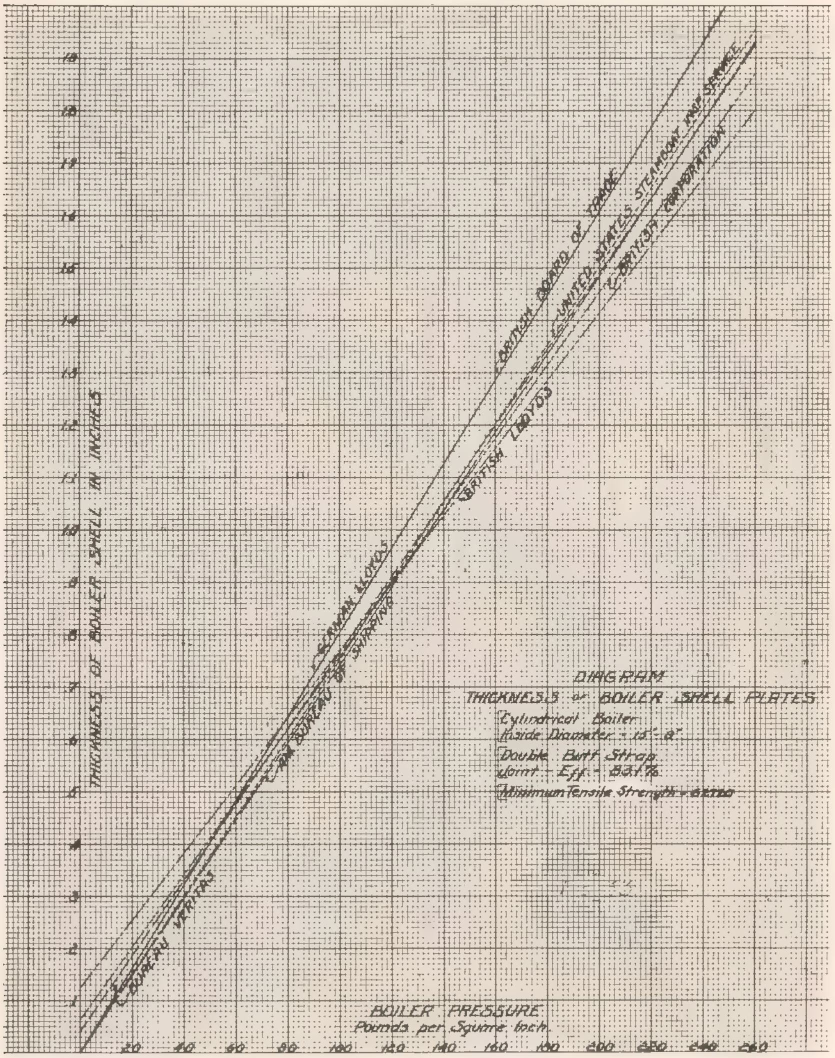
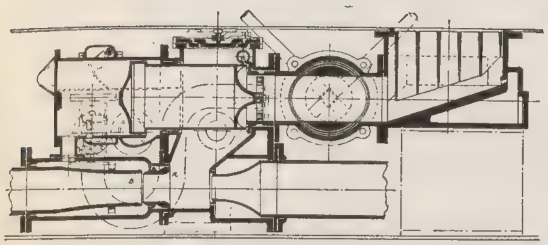


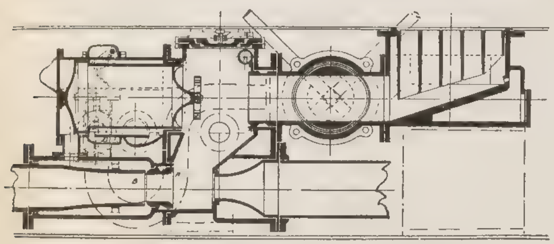
Fig. 27.

division of boiler- and engine-room spaces and the higher efficiency at which boilers are operated. The principal means of communication are loud-speaking telephones, speaking tubes, electric telegraphs, electric smoke indicators, electric firing indicators, regulated by the engineer from the engine room, and electric water-tight door signals. The space allowed for this



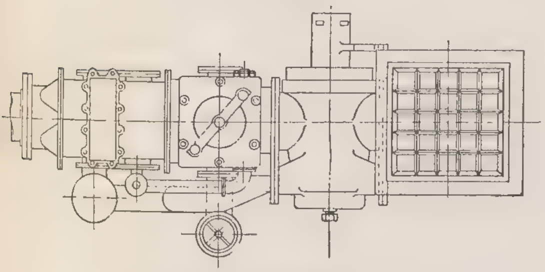
EXPELLER SHUT OFF.

Scale $\frac{1}{12}$ Full Size.



EXPELLER WORKING

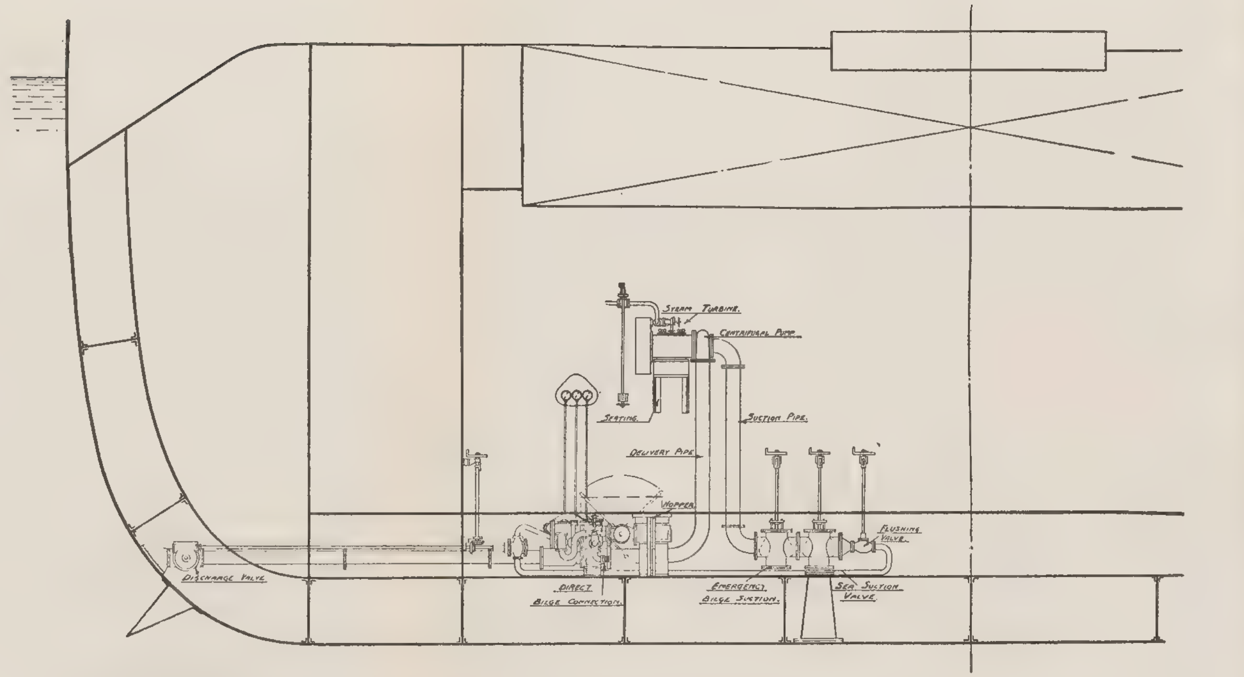
Scale $\frac{1}{12}$ Full Size.



PLAN ON STOKEHOLD FLOOR

FOOT-PLATES REMOVED

Scale $\frac{1}{12}$ Full Size.



SECTION OF SHIP SHOWING GENERAL ARRANGEMENT OF STONE'S ASH EXPELLER.

NOTE:—THE DISCHARGE MAY BE LED OUT AT ANY POSITION FROM IMMEDIATELY BELOW THE WATER LINE TO THE KEEL AS MAY BE FOUND CONVENIENT IN RELATION TO OTHER FITTINGS.

Fig. 28.

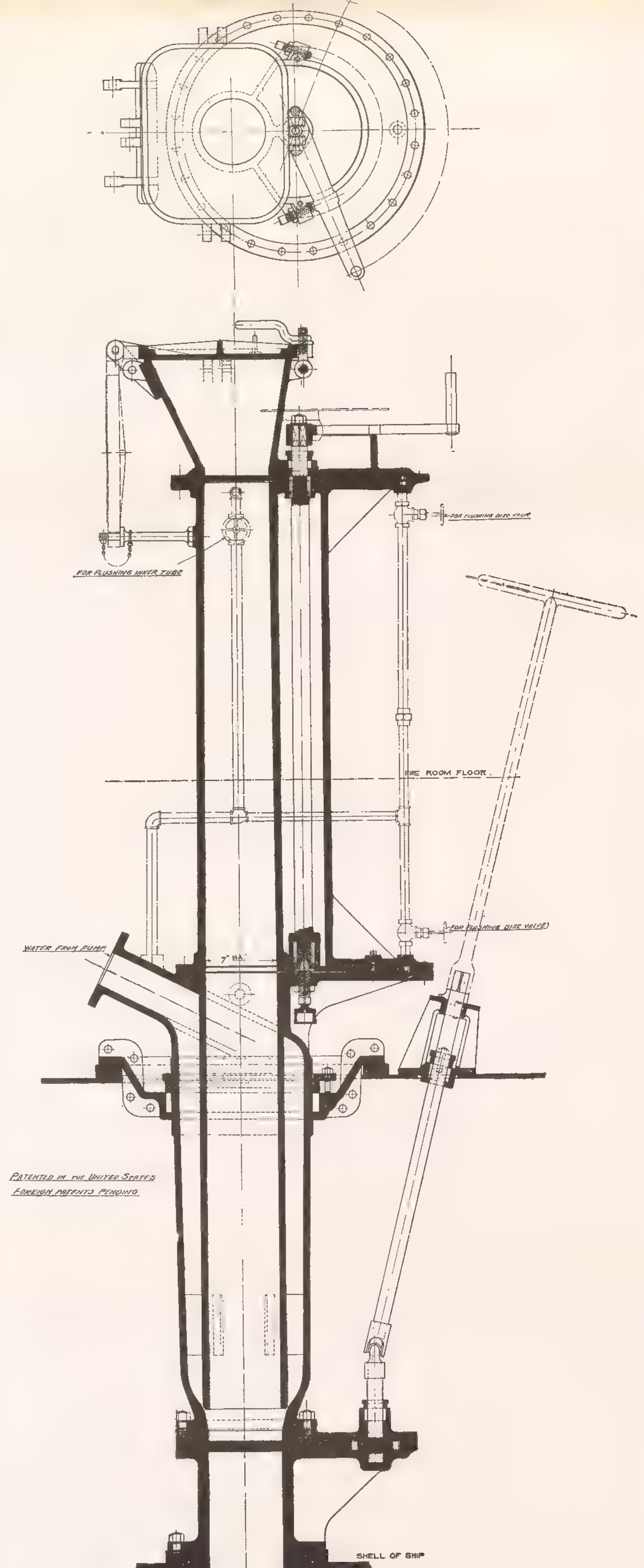


Fig. 29 Metten Ash Expeller—U. S. S. "Cyclops."

paper does not permit of much detail description of these various devices, but excellent instruments for these services are now made in several countries.

Telegraph Systems are usually fitted for transmitting orders from the engine room to the fire-room and from any one fire-room to the engine room. There is one transmitter located in the engine room and one in each fire-room, each instrument being a combined transmitter and indicator. The signals consist of lamps mounted in the instruments behind glass plates which cover orders or indications perforated in the face of the dial. Attention in each room is called to the visual signal by means of a gong which rings once for each signal given.

Firing Indicators for controlling the firing of boiler furnaces have been adopted in many naval and large merchant vessels and it is only by such means in large installations that the maximum coal economy and minimum smoke production are realized. With this system the boiler furnace doors are numbered and an indicator provided in each stokehold signals these numbers in rotation at regular intervals, at the same time sounding a gong to call attention to each change of signal. The interval between successive signals is controlled by the regulator placed in one of the engine rooms.

Smoke Indicators. The density of smoke is best defined by reference to the Ringelmann chart as published by the U. S. Geological Survey.

Smoke indicator systems are sometimes installed where it is difficult to observe the smoke from the fire room, and especially in connection with fuel oil. In naval vessels where it is desired to cover the manoeuvers of the vessel under cover of a dense cloud of smoke, a means of giving this information to the boiler room is necessary. The transmitter for this system may be placed on the bridge and connected to indicators in the boiler rooms. By these indicators the freedom from smoke or the density of the smoke or the amount of smoke desired may be communicated to the boiler rooms in a similar manner to orders given on the electric telegraph.

In oil-burning boilers it is customary to provide small glass-covered openings in opposite sides of the uptake passage as the smoke leaves the boiler. An electric light placed at the back

opening may be clearly seen at the front opening if no smoke is present. A mirror is placed at the front opening to reflect the image where it may be seen by the operator of the oil burners.

Electric pyrometers for uptakes and stacks may be mentioned here, as the temperatures in these places are so closely connected with the efficient operation of large marine-boiler installations. The dials of such pyrometers may be located in the boiler room or elsewhere, and wires led to thermo couples placed in various parts of the gas passages; by the turning of a switch, connection is made to any desired couple, which immediately indicates the temperature on the dial.

ANALYSIS OF FLUE GASES.

Facilities for accurately and quickly analyzing flue gases have been the means of largely increasing the economy of marine boilers. Several forms of apparatus are now used aboard ship by which such analyses can be made continuously and a permanent record automatically made of the amount of CO_2 in the gases.

The work of Professor Robert H. Smith in connection with this subject, combustion problems and superheating has been very valuable, as has also the work of the U. S. Geological Survey.

HANDLING OF REFUSE AND ASHES.

The past few years have seen the further application of hydraulic ash ejectors and ash expellers to both naval and merchant vessels. Several systems have been developed which require a steady supply of water at pressures varying from 15 pounds to 300 pounds, depending upon the system used, and the draft and the size of the ship. With the See type of ash ejector, the discharge is above the water line, and for this reason it is now seldom adopted in naval vessels, owing to the necessity of piercing the armor and torpedo bulkheads. This has led to the development of the hydraulic ash expeller, which employs the principle of an induced water current. The ashes are carried into the discharge pipe and forced through the bottom of the vessel or out through the side of the ship below the water line. There are automatic safety features embodied in most

designs. In installing this type of ejector the discharge must be so placed and directed as to prevent ashes and cinders from being drawn into the sea suctions. Figs. 28, 29, 30 and 31 represent the Stone, the Metten and the Palen-Burlingham types of these expellers.

Refuse hoists are usually fitted even with oil-burning installations, and ash hoists are also installed in conjunction with ash expellers. Such hoists consist of automatically-controlled double-cylinder engines, steam tubes or tubes operated by air pressure or by the vacuum system. Ash hoists are often arranged with self-dumping buckets which empty into chutes, where the ashes are flushed overboard. Some vessels have chain ash elevators which discharge to similar hoppers and chutes.

MECHANICAL AND NATURAL DRAFT.

The practice of fitting Howden draft in connection with Scotch boilers is still increasing. It is a tribute to the foresight of Mr. James Howden that the Howden draft installations of today are so similar in most essential points to the installations which he made fifteen or eighteen years ago.*

Howden draft is best adapted for use in connection with Scotch boilers, although some large installations of water-tube boilers have recently been made using this system of draft. The Howden principle of automatically closing all dampers to each furnace as fired makes the system safe and well adapted for Scotch boilers with separate combustion chambers. In applying this draft, or any similar system, to large common furnace water-tube boilers the air must be wholly or partly cut off when firing; thus a large grate area is affected, and for this reason, with such boilers, induced draft which does not require closing of the draft dampers when firing is sometimes more practicable.

A few years ago when induced draft with air-heater tubes was more commonly applied to Scotch boilers than at present, dampers in the uptakes for each furnace were arranged to be

* Mr. Howden in a late paper on "Forced Combustion in Steam Boilers", reviewed this subject and stated that "The honor of first using a blowing fan to accelerate combustion in a steamboat belongs to Mr. Edwin A. Stevens of Bordentown, New Jersey, who in 1827 in the 'North America', fitted boilers with closed ash pits into which the air of combustion was forced by a fan".

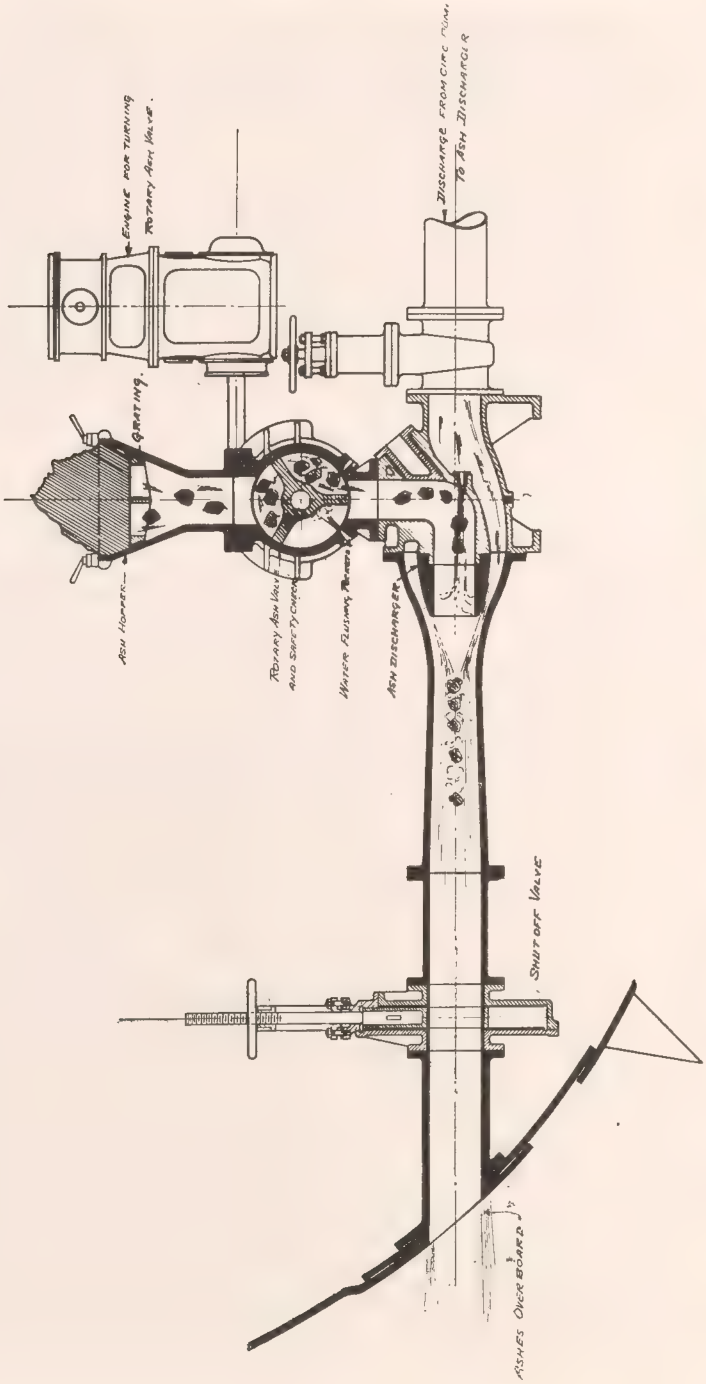


Fig. 30. Section Showing Operation Palen-Burlingham Underwater Horizontal Hydraulic Ash Discharger.

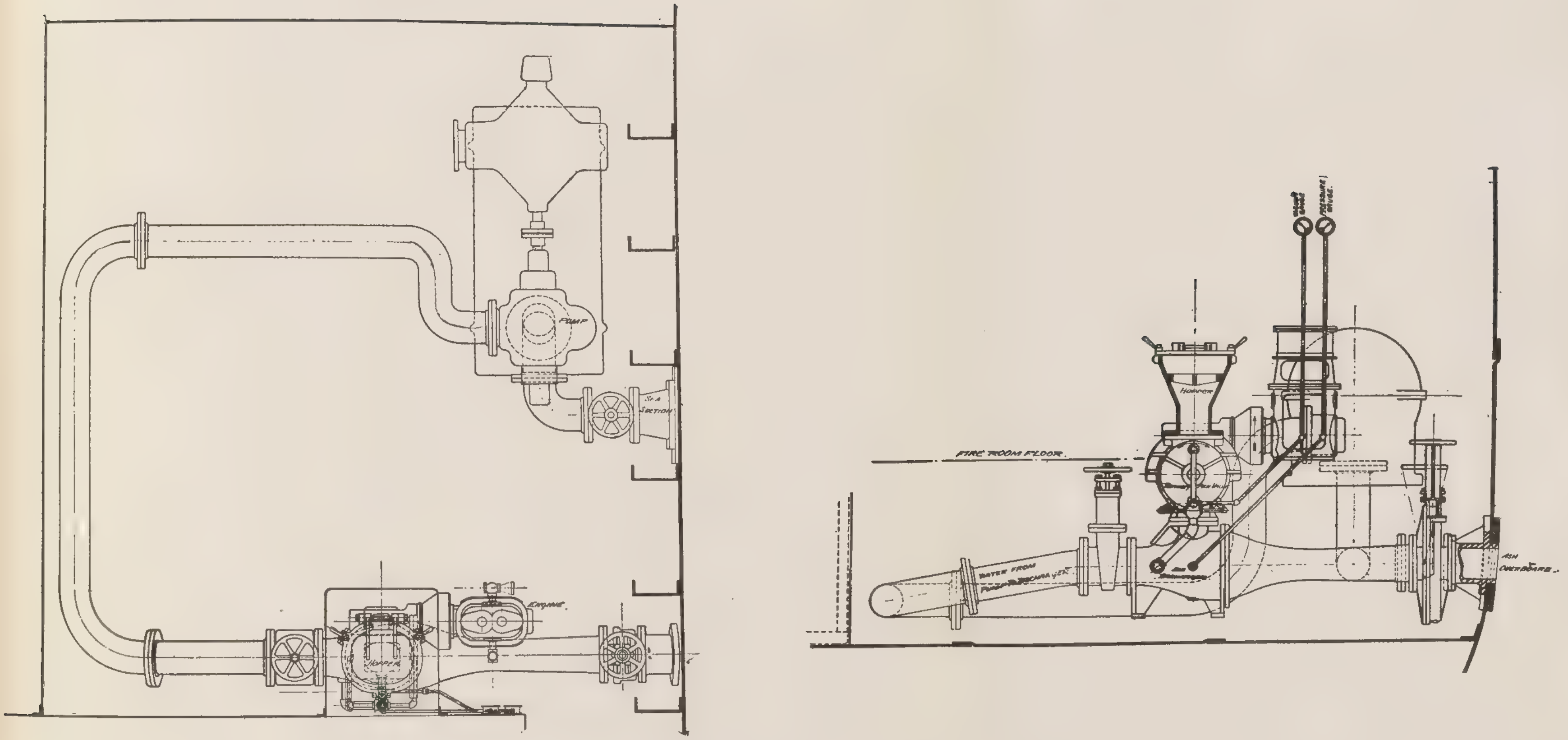
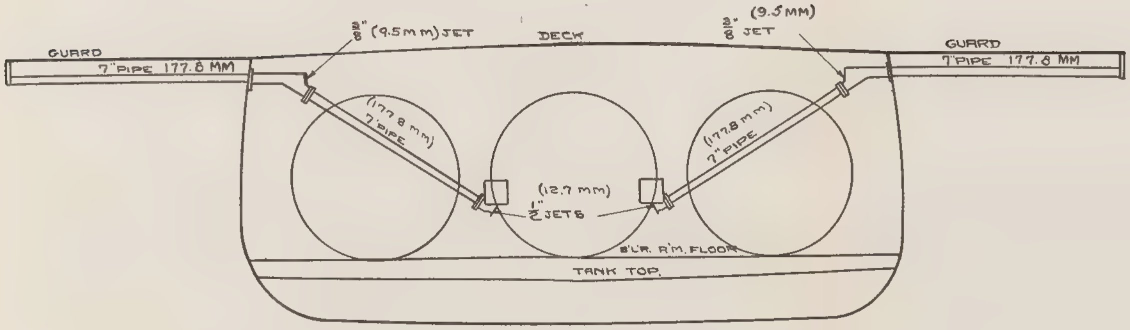


Fig. 31. Arrangement of Palen-Burlingham Underwater Horizontal Hydraulic Ash Expeller.



SECTION SHOWING ASH GUNS
TWO GUNS THUS IN EACH FIRE HOLD

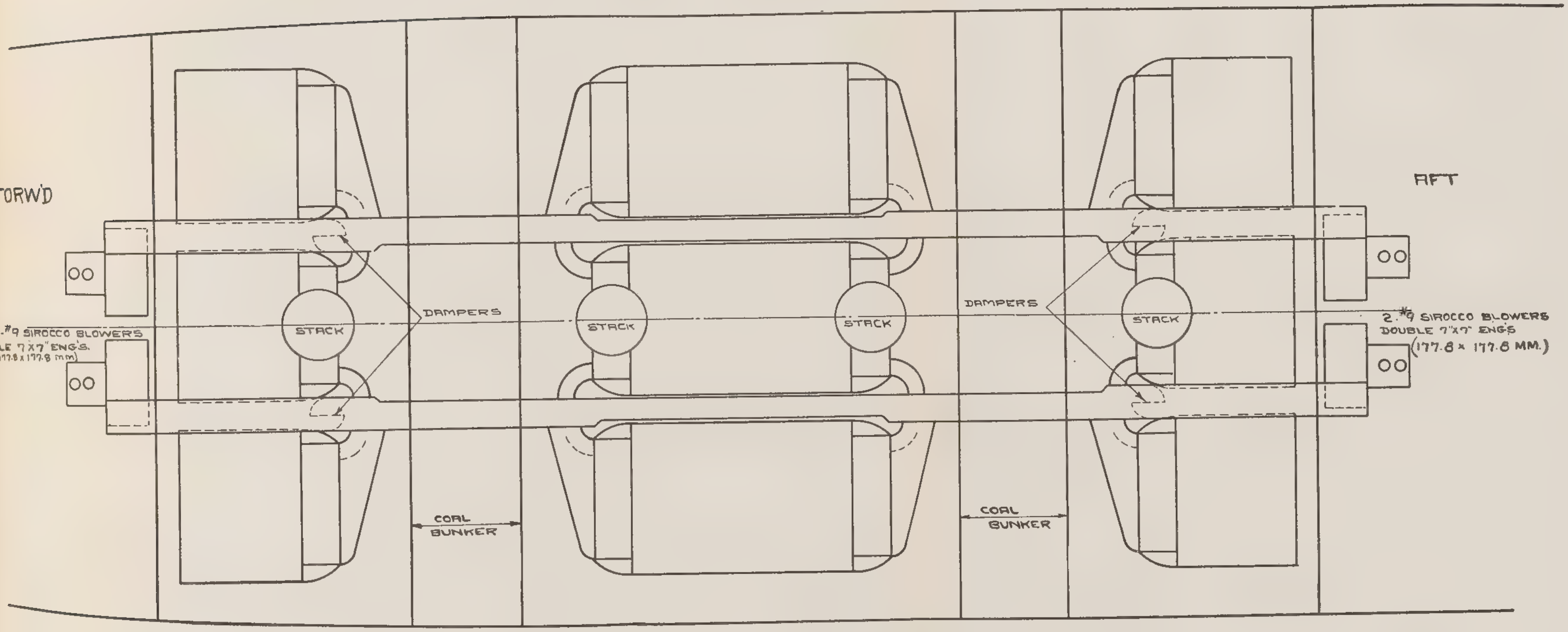


DIAGRAM OF BOILERS AND HOWDEN FORCED DRAFT ARRANGEMENT
GREAT LAKES STEAMER "SEE AND BEE."

Fig. 32.

automatically closed when firing. The principal objections to induced draft are the increased size of fans, the difficulties of arranging the air ducts, and the fact that a large amount of cold air is allowed to enter the furnace when firing, due to the fan suction.

Some water-tube boilers are now designed with heating surface, gas passages and circulation so proportioned and arranged as to reduce the uptake temperatures sufficiently for good economy without the use of air-heater tubes.

It has been suggested in connection with large electrical propelling machinery installations, in which it is necessary to ventilate the main generator and propelling motors, to adopt the arrangement of placing the main power-generating units amidships, with boilers located both forward and aft of these units, and with the propelling motors aft of the after boiler installation, so as to best utilize the warmed air from the ventilation ducts of the electrical machines in connection with the forced draft system of the boilers. This also has the additional advantage of reducing the length of the steam piping to the turbo generators, which is a decided advantage in large installations, owing to less drop in the steam pressure at the turbines.

With fire-tube boilers, where the draft is sufficient it is advantageous to use retarders, either of the spiral type or other form, in the boiler heating tubes, and in some cases such retarders are fitted in the air-heater tubes. With oil-burning Scotch boilers it is feasible to install retarders even when designed for natural draft, and considerable gain in efficiency is effected thereby.

With the best-designed Scotch boilers, with Howden draft and modern machinery, very economical results are obtained.

The Scotch boilers shown in Fig. 1 were fitted in the oil-tank Steamship "Topila" with Howden draft and with White fuel-oil burners. This installation is giving very economical results.*

* Mr. A. S. Hebble, Superintending Engineer of the Southern Pacific Company, states that he has obtained on a trip from New York to Tampico, using Navy fuel oil of 26° Baume gravity containing about 19,500 B.t.u.'s per pound (10,730 Cal. per kg.), a fuel oil consumption of 0.875 lbs. (0.397 kgs.) per horsepower per hour, based on the I.H.P. of the main engines and an allowance of 7% for auxiliaries and for steam used in the oil heaters and in the cargo and fuel-oil tank heater coils. The same vessel for the last 15 voyages, prior to June 23, 1915, running between Tampico, Mexico,

During the last decade considerable improvement has been made in the arrangement of large fire-room installations fitted with Howden draft. In some well arranged installations the fans are placed in pockets adjacent to and opening into the stokeholds, so that the air for combustion is drawn down the ventilators and across the fire-rooms to the Howden draft fans. Where this arrangement is neither desirable nor practicable, the blowers may be located on deck above the boilers, in which case suction ducts are sometimes led from the fans to the stokehold, and adjustable suction openings are provided in the fan casings, communicating directly or by ducts to the fan rooms to insure ventilation. In smaller installations the fans are usually fitted in the engine room with discharge ducts leading to the heater boxes, in which case the suction is taken either from the engine room or from the fire-room or from both spaces, as may be desired.

With large fan installations, the capacity of the units and the arrangement of fan discharge ducts and dampers should be such as to permit the closing down of any blower for repairs or attention without seriously affecting the operation of the system.

Such an arrangement is indicated in Fig. 32, Diagram of Boilers and Howden Forced Draft Arrangement on the Great Lakes Side Wheel Steamer ''See-and-Bee''.

Some of the advantages claimed for heated mechanical draft

Galveston, New Orleans and Sabin Pass, New York and Tampico, using Mexican crude fuel oil, and on the same basis of power as on the trip previously referred to, has averaged a consumption of 0.981 pounds (0.445 kgs.) per horsepower hour. The fuel oil for these trips showed an average analysis of about the following:

Specific gravity at 60 degrees F. (15.6° C.) 0.9799.
Baume gravity at 60 degrees F. (15.6° C.) 12.87.
Flash point, degrees F. 139 (59.5° C.).
Water 1%.
Heat of combustion per lb. of oil, B.t.u.'s 17,976 (9980 cal. per kg.).

It is important to keep Mexican crude oil in the bunkers and cargo tanks at a comparatively high temperature, approximately 100° F. to 110° F. (38° C. to 43° C.), to facilitate pumping and discharging, and this temperature in the case of the ''Topila'' is maintained in the cargo tanks during the voyage. The allowance therefore of 7% over the main engine I.H.P. probably does not represent as great an expenditure of auxiliary steam consumption as actually obtains.

are: Smaller first cost; better utilization of the waste gases, with the resulting greater economy; more satisfactory regulation, with increased reserve power when the installation is correctly proportioned; economy of space and less weight; and, furthermore, such installations are best adapted to the fitting of superheaters, either as an original installation or as a later change.

For several years past large installations of fans, either in connection with Howden draft or the closed fire-room system or as fire-room ventilating fans for natural draft, have been

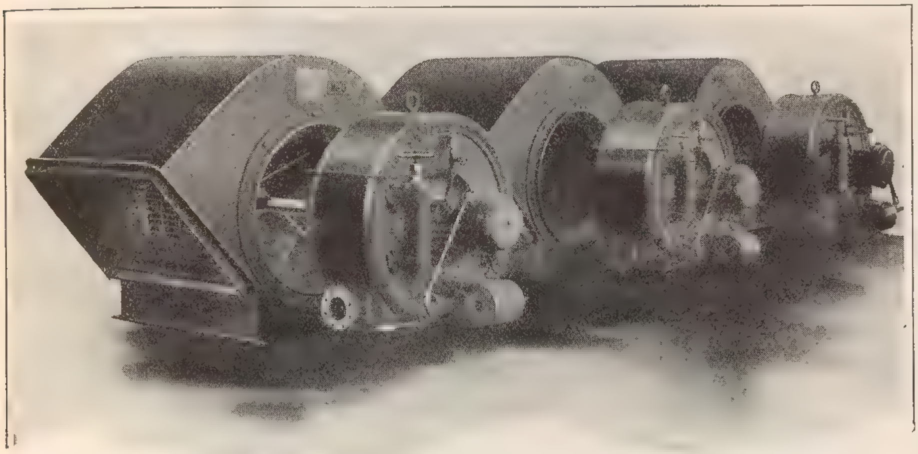


Fig. 33. Double-Inlet Sirocco Forced-Draft Fans Driven by Direct-Connected Steam Turbine for Training Cruiser for the Chinese Commission. Capacity Each Fan 30,000 cu. ft. per Minute (850 cu. m.) 3″ Static Pressure (76 m.m.) 1220 Revolutions.

made with high-speed fans of either the steel-plate type or the multi-vane type driven by electric motors or steam turbines. Such installations are sometimes fitted with the fans arranged in pairs with a steam turbine or a variable-speed shunt-wound self-ventilating motor between each pair. Water gauges and tachometers are provided at the fans. If electric motors are used, the controllers are arranged to be operated both at the fans and in the stokeholds and are made to protect the motors against over loads and failure of supply. The motors can be stopped by press buttons located in the fan rooms and the stokeholds.

Closed fire-room installations are usual in naval work.

Fig. 33 shows "Sirocco" fans driven by turbines direct connected for forced draft, on a training cruiser for the Chinese Commission.

When two or more motor-driven fans of this character are installed for each closed fire-room it is advisable to fit an automatic damper at each fan discharge so balanced that if a circuit breaker for any fan motor blows, the air pressure in the

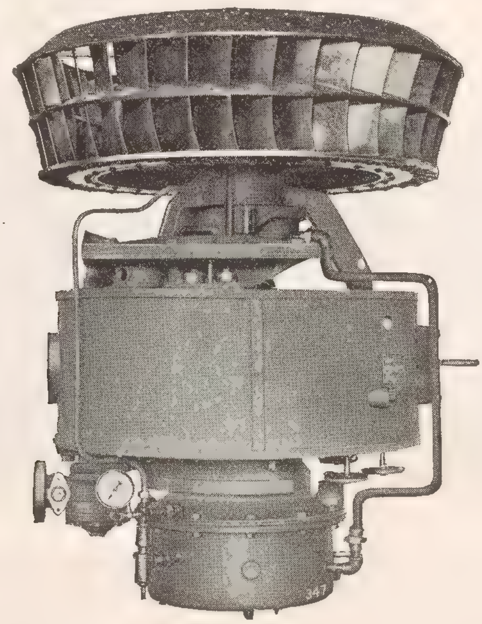


Fig. 34. Terry Vertical Spindle Two-Bearing Radial-Flow Forced-Draft Fan for Italian and U. S. Destroyers.

fire-room will not reverse the motor and due to reduction in the air pressure throw a large excess load on the other fans.

The turbine-driven fan is probably the most compact and lightest outfit which has been put on the market for outfits requiring moderately-high air pressures.

Fig. 34 shows turbine-driven fans built by the Terry Steam Turbine Company designed for forced draft on Italian and U. S. destroyers. The casing is split vertically; a small portable crane is arranged to take the weight of the covers when dis-

mantled. Each fan for the Italian boats is designed to deliver 34,000 cu. ft. (963 cu. m.) of air per minute against an air pressure of 5.9 in. (150 mm.) water when running at 70 horsepower and at 1400 revolutions per minute. These fan wheels are 37½ inches (952 mm.) diameter.

Turbine-driven fan units have been fitted in several destroyers arranged to work compounded, the high pressure exhausting at

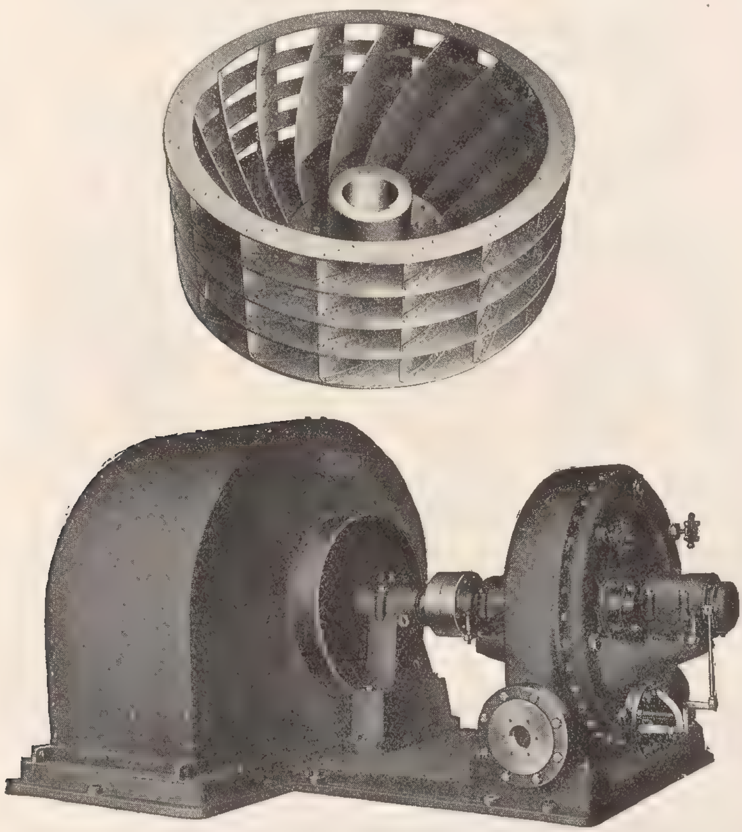


Fig. 35. Sturtevant Horizontal Turbine-Driven Forced-Draft Fan and Fan Wheel —Battleship "Pennsylvania."

from 50 pounds to 60 pounds (3.4 to 4.1 atmos.) pressure, the low pressure exhausting at about 10 pounds (0.7 atmos.). This results in a saving of about 20 percent in the water rate as compared with single units.

Fig. 35 shows one of twelve Sturtevant horizontal steam tur-

bine-driven forced-draft fans which are being fitted in the U. S. Battleship "Pennsylvania". Each blower has a 25-in. (635 mm.) cone fan in a scroll casing with double inlets, and is direct connected by a flexible coupling to a Sturtevant steam turbine. Each unit will deliver 17,500 cu. ft. (496 cu. m.) of air per minute at 4 in. (102 mm.) air pressure in the fire-room when making 2100 revolutions per minute, and is able to maintain an

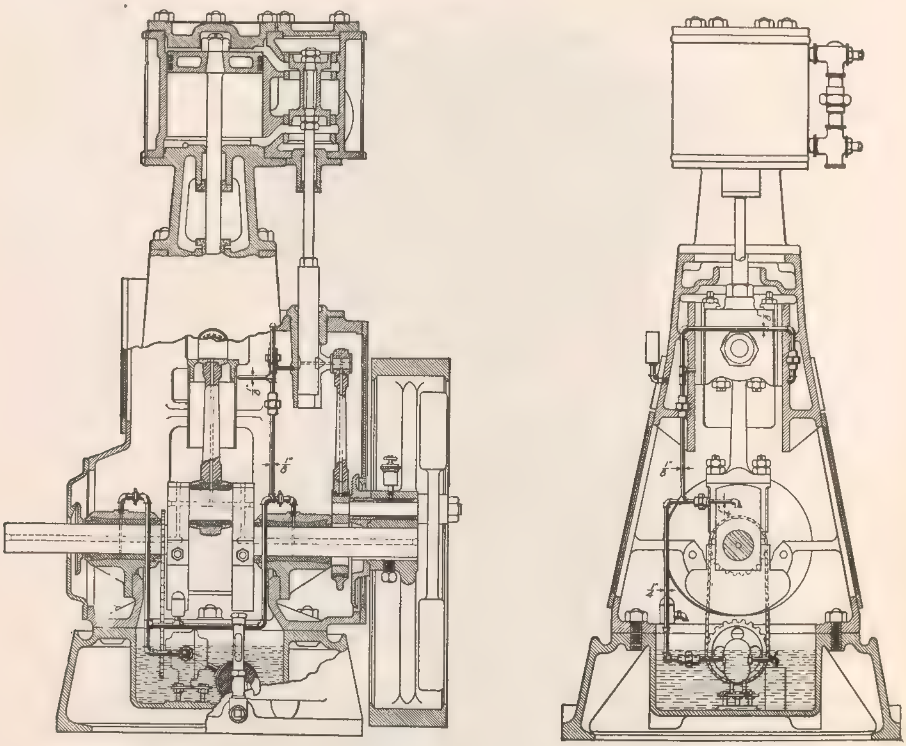


Fig. 36. Sturtevant Fan Engine, Forced Lubrication.

excess capacity of 20% with steam pressure of 250 pounds (17 atmos.) with an exhaust pressure of 15 pounds (1 atmos.) gauge pressure at the turbine.

Each turbine is fitted with an automatic governor and forced lubrication, which is closed to prevent dust from coming in contact with the oil.

The Keith fan has shown great efficiency and is well adapted to mechanical draft purposes.

Only a few years ago when it was proposed to install steam turbine-driven fans for this class of work, strong criticisms were raised that such fans would be unsatisfactory. It is now demonstrated that these fans are efficient, safe, economical and reasonably quiet. Similar fans to those mentioned above are

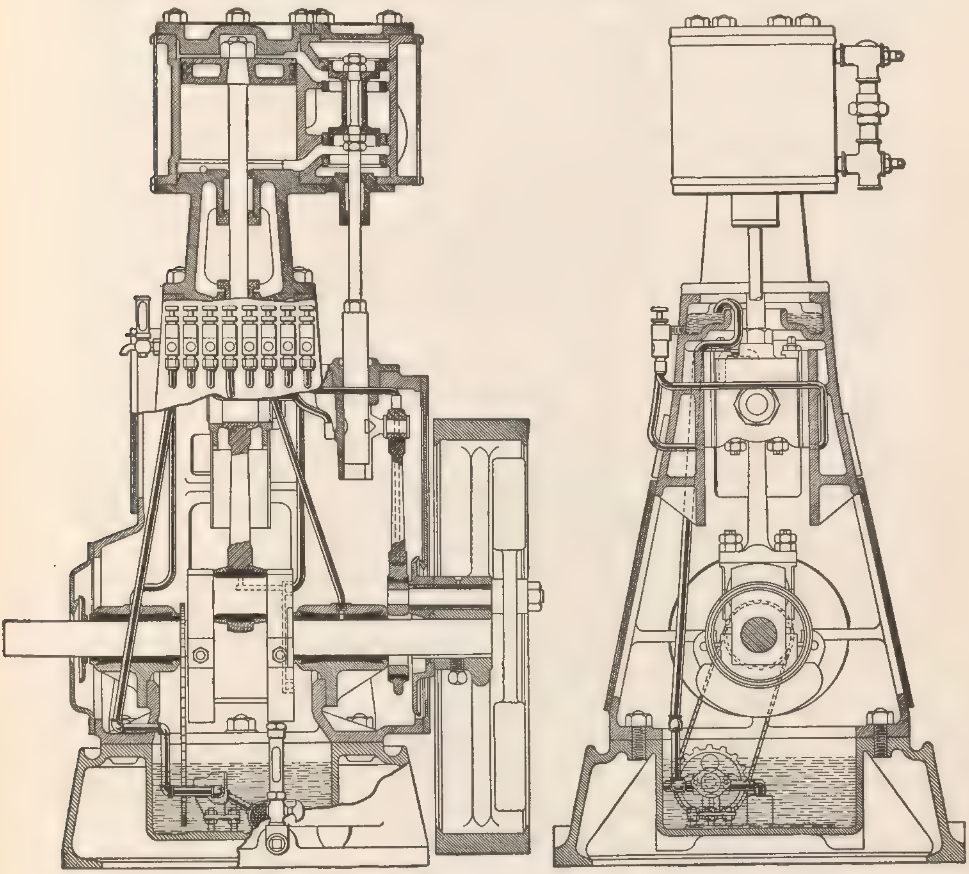


Fig. 37. Sturtevant Fan Engine, Automatic Gravity Lubrication.

now made by the principal fan builders, who deserve much credit for bringing these units to the degree of efficiency and dependability which has been realized.

When two or more turbine-driven high-speed fans are installed in a single fire-room, the speed of each fan must be practically the same to obviate the fans working against each other.

The fan speeds may be adjusted by a single valve at each turbine and all fans slowed down or speeded up, as conditions require, by the manipulation of one valve supplying steam to all the turbines.

Some steamship lines favor natural-draft boilers for their vessels, but in large installations provide forced fan ventilation to the fire-rooms. Rocking grates with natural draft are also fitted as an assistance in working the fires. Mechanical stokers have been tried in several installations, but the problems of their adoption in marine work have not yet been solved.

BOILER FEED PUMPS.

The tendency in steam feed-pump design has been to eliminate flat surfaces, substituting spherical and cylindrical parts to stand the high pressures and still maintain as light weights as feasible.

The long-stroke vertical simplex boiler-feed pump has gradually developed towards a better steam economy, a more positive operation and greater ease of overhauling.

The high boiler pressures of 250 to 295 pounds (17 to 20 atmos.) and the use of superheat have required a valve gear that will operate without lubrication.

The Blake and Knowles Company have developed a design of suction and discharge valves, shown in Fig. 38, which permit of the withdrawal of the entire set of valves by the removal of only the covers and lock nuts.

Bevel-faced wing-guided valves are sometimes used and also valves of the three-disc type with suitable valve decks.

Another design, Fig. 39, provides annular double ports which permit of a very low lift of valve and a minimum slip and noise, facilitating high speed.

Rubber valves used in connection with cold-water pumps are ordinarily subject to considerable wear. This difficulty has been practically eliminated by the development of the rotating valve. The feature of this design is the partial rotation of the valve at each stroke as it is lifted from its seat, which causes the contact between the valve and the seat ribs to change continuously, thus distributing the wear over the entire face with the result of greatly increasing the service of the valve. This

rotation is secured by inclining the ribs of the valve seat so that the water in passing impinges on the valve at an angle.

Fig. 40 shows a feed pump of the simplex vertical type

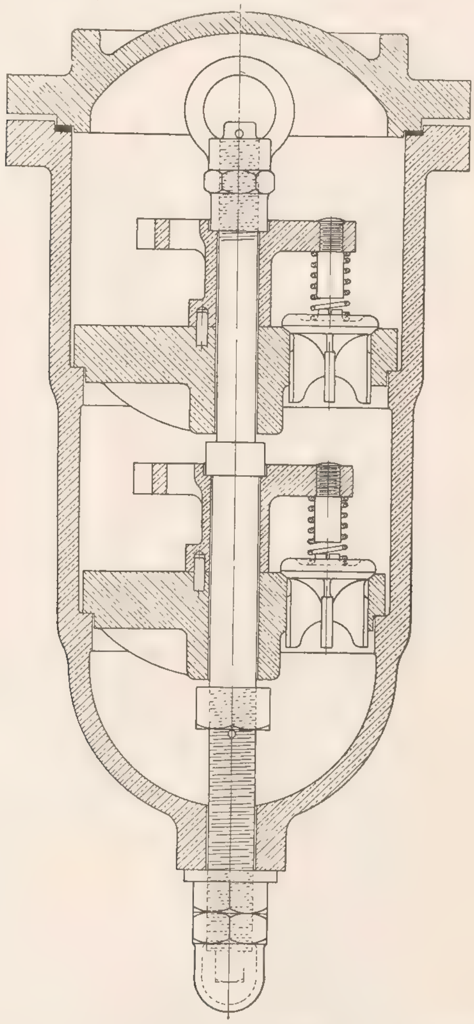


Fig. 38. Blake & Knowles Feed Pump Valve Arrangement.

built by the Warren Pump Company. This design likewise incorporates the triplex suction and discharge valves. On test*

* Test of a Warren vertical single boiler feed pump, Naval Engineering Experimental Station, Annapolis, Journal A. S. N. E., May 1913, Vol. XXV.

this pump showed, when fitted with such valves, a slippage of less than 1½% at a piston speed of 100 feet (30.5 m.) per minute, and less than 9% at a piston speed below 24 feet (7.3 m.) per minute, with delivery pressures of over 250 pounds (17 atmos.). The steam consumption on these two tests referred to averaged about 2% of the discharge capacity of the pump at the

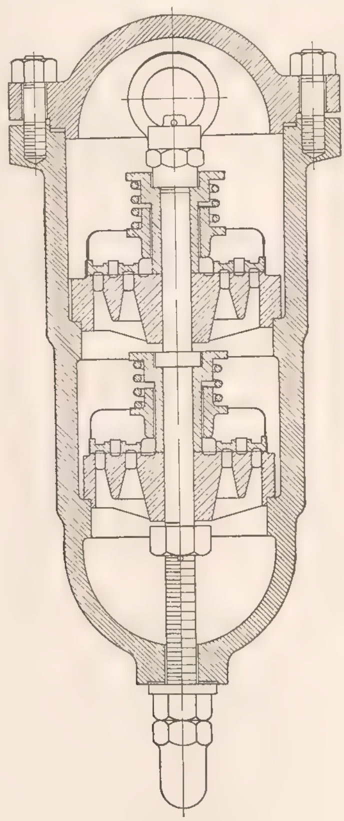
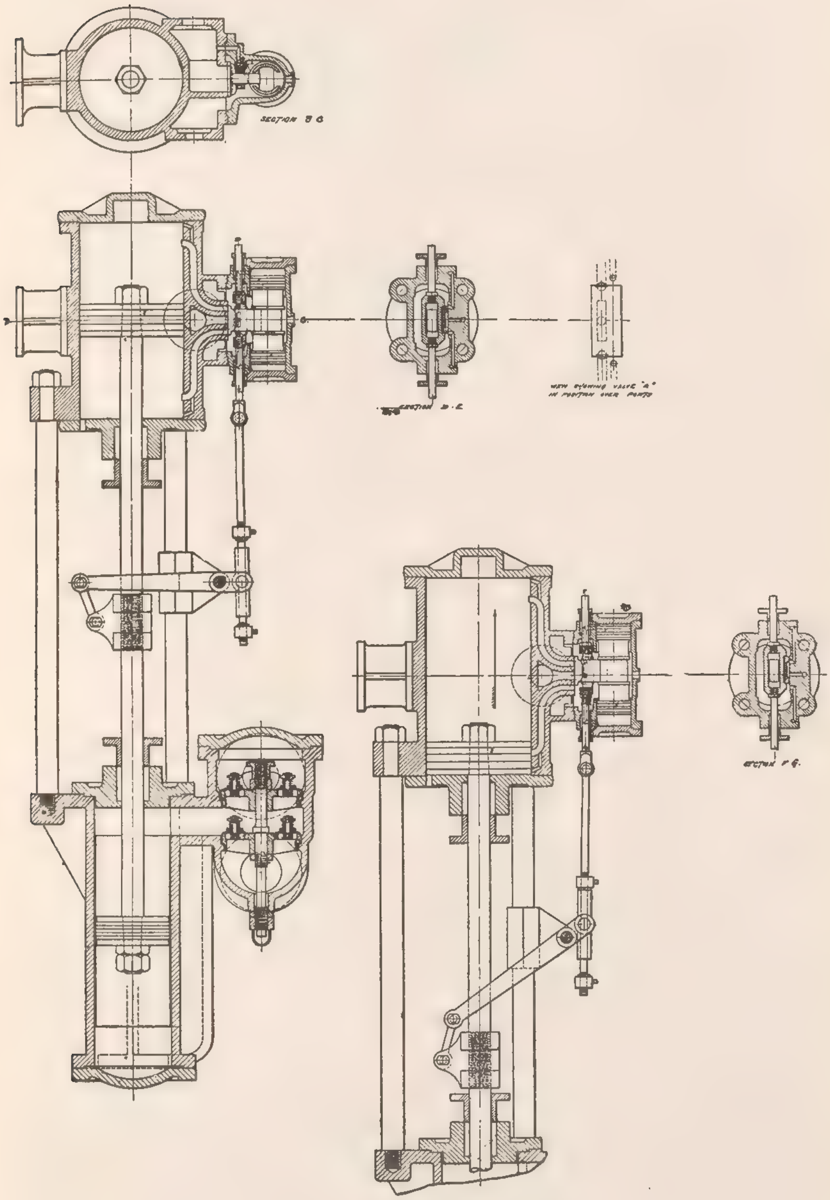


Fig. 39. Blake & Knowles Annular Double Ported Feed Pump Valves.

higher rate and less than 2.8% at the lower rate. The pump is especially easy to start without preliminary warming up.

In recent years rolled Monel metal has been used in place of composition for pump piston rods and cylinder linings, for which purpose it has many advantages owing to its high tensile strength and great resistance to corrosion.

Direct-acting pumps are now being built with a cut-off



DETAILS OF WARREN PUMP.

Fig. 40.

arrangement on the steam valves. This operates on the back of the main slide valve, which gives an improved steam economy and smooth quiet action, with quick reversal but with a minimum shock in the pipe lines. Direct-acting pumps are well adapted to automatic control either by the discharge pressure or by feed heater or tank-float control.

Centrifugal boiler-feed pumps have been adopted to a comparatively small extent, in some cases for boiler pressures as high as 295 pounds per sq. in. (20 atmos.). The continuous flow largely eliminates the shock through piping, valves and checks, although this can also be accomplished by the proper use of air chambers in connection with direct-acting long-stroke pumps.

As Mr. Weir has pointed out,* the feed pumps should be driven by the same source of power that actuates the main machinery. It is to be noted in this connection that turbines are being successfully developed for such pumps in a considerable amount of high-grade merchant and naval work. The feeling of caution as to the use of centrifugal feed pumps is changing to one of more assurance and confidence.

FEED-WATER HEATERS.

The importance of feed heating is being more generally recognized in recent years. This is largely due to the fact that the amount of auxiliary exhaust in present installations is greater, owing to an increased number of independent auxiliaries.

In boilers where the feed is taken in so as to extract the greatest amount of heat from the escaping gases, feed heating is not so essential; but in most types of boilers it is important to fit auxiliary exhaust feed heaters, both from the point of economy of fuel and boiler maintenance.

Steam feed-water heaters are fitted of two principal classes —the contact type, which is found in many trans-ocean liners, and the surface or pressure type which is used in both naval and merchant work. The contact type makes it necessary to employ an additional pump for lifting the water from the hot-well to

* "Development in Auxiliary Units Between Exhaust Pipe and Boiler", Transactions of Institution of Engineers and Shipbuilders in Scotland, October 1912.

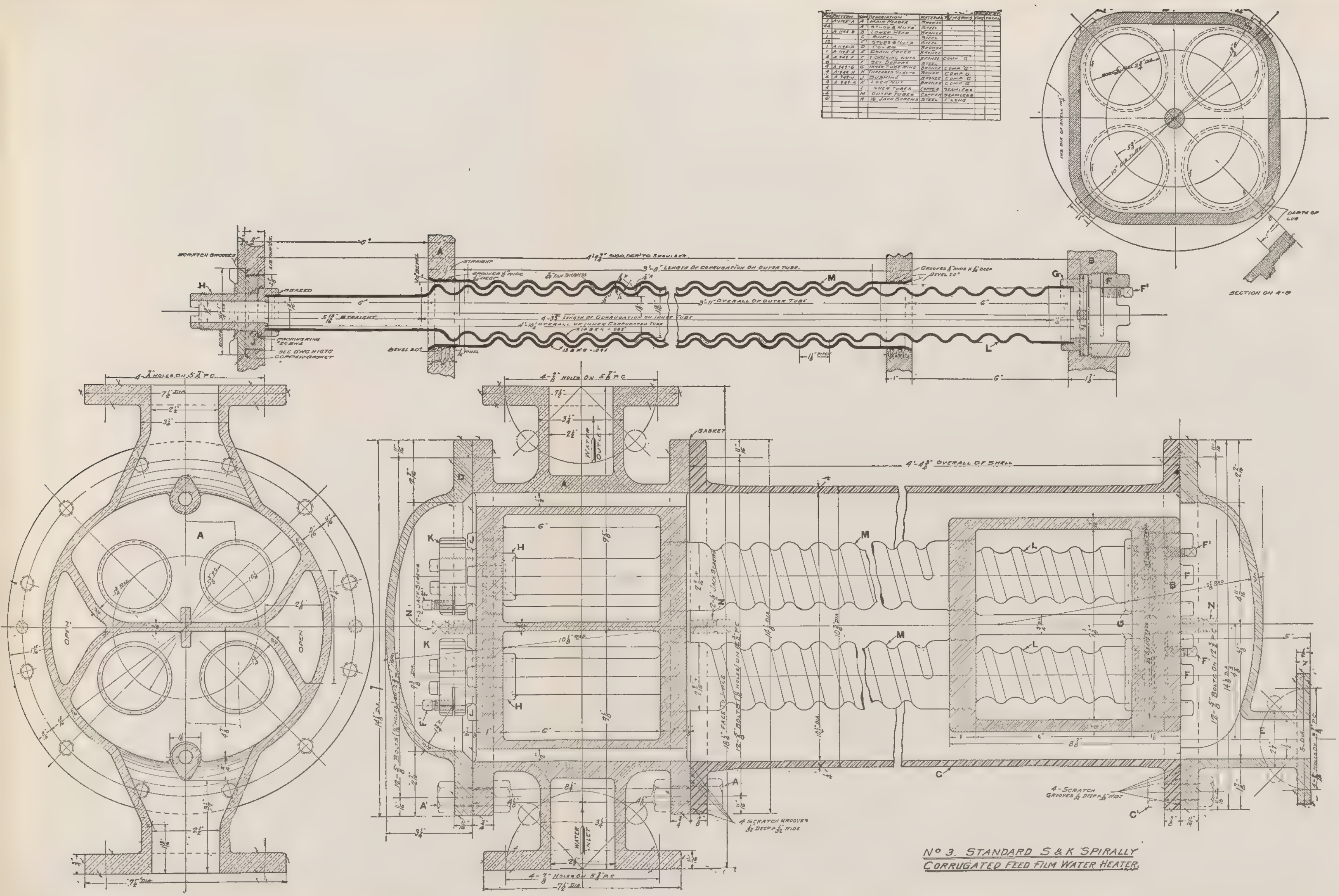


Fig. 41. No. 3 Standard Schutte & Koerting Spirally Corrugated Feed Film Heater.

the heater and also entails handling the heated feed in the main feed pumps. This in some cases has proven unsatisfactory, but the ability of this heater to eliminate injurious gases from the feed and the high efficiency are points in its favor, and large numbers of this class of heater, including the Weir and Blake types, have been fitted.

If oil is used so that there is any possibility of its entering the steam or exhaust, special precaution must be taken to eliminate it. This heater also requires to be placed so high that it usually cannot be adopted for naval work. This point has been brought out and the subject of feed heating ably discussed by Mr. Weir in his paper above referred to.

The surface or closed type of heater is also used in merchant work and extensively in naval work. In some instances it may be advantageous to install both types of heaters in conjunction, as outlined by Mr. Weir. The surface type permits of higher feed temperatures than the contact heater.

The conditions governing the efficiency of surface heaters are lucidly presented by Prof. Leo Loeb.* After discussing the thermal resistances of several metals, water and air, Prof. Loeb states: "It is evident, therefore, that a metal tube will transmit all the heat that is presented to its surface and that the controlling resistances lie in the two films which cling to the metal surface. The condensing steam presents a wet surface, so that resistances on the two sides are much alike.

"The formation of such a film is a friction effect. The microscopic irregularities of surface of the metal walls tear off particles of the fluids passing and prevent these particles from being swept along with the major current. The more completely these particles of water are dislodged and swept from the surface, the better able are other colder particles to replace them and absorb their share of heat from the surface. Hence the problem in producing high transmissions in heaters is the destruction of this water film by a scrubbing action produced by a high velocity along the heating surface. When the limit of heat transmission has been reached on the water side by a velocity that is entirely practical, the controlling resistance has passed to the steam side,

* "Heat Transmission and Tube Length in Marine Feed-Water Heaters", Journal of the A. S. N. E., May 1915.

and the only way to further increase heat transmission is to sweep away the film on the steam side."

Prof. Loeb clearly outlines other conditions encountered in this type of heater and discusses heat transference as affected by temperature differences, the high transfer rates which may be obtained with water agitation, and the deleterious effect of air in reducing the efficiency of such heaters.

The experiments made by Prof. Loeb show the high efficiency possible with the Schütte and Koerting film type of heater. This heater is illustrated in Fig. 41.

BOILER CORROSION.

The corrosion of boilers has been the subject of much study and discussion. The principal causes of corrosion are the presence in the water of air and salts; acidity of the water due to salts and the use of animal or vegetable oils; and galvanic action. Corrosion is greatly increased by sluggish circulation. The feed water absorbs air and with it probably a greater percentage of oxygen than of nitrogen; salt water also absorbs more air than fresh water. With sluggish circulation the small bubbles of air cling to the metallic surfaces and attack the metal, especially in places where these bubbles are not continuously swept off by the water currents. Rapid circulation also retards scale formation.

Corrosion may be minimized by freeing the boiler of air, and therefore it is especially important to stop all air leaks in pipe connections, condensers, etc. Heating the water tends to drive out the air and this is one of the advantages of the use of feed heaters which heat the water before it enters the boilers. It is also important to use pure water and avoid all water leaks in condensers which will tend to salt up the feed. It is probably advantageous to admit the feed to the steam space or slightly below the liberating surface of the water in the boiler to allow the air contained in the feed to separate.

Numerous boiler compounds have been marketed to remedy the troubles of boiler corrosion and scaling, but these should be used with caution, as some compounds are probably responsible for more serious and dangerous troubles. Zinc plates secured in the boiler are a preventive of corrosion, as is also the use of lime and soda as conditions require.

Some progressive boiler manufacturers issue instructions relative to the causes and the preventive steps to be taken and remedies to be applied in connection with corrosion and, in addition, furnish with each marine-boiler installation a testing kit to enable the engineer to ascertain the condition of his boiler feed and to take steps to minimize the troubles of corrosion and scale formation.

CONCLUSION.

In the last decade no revolutionary inventions have been made in this field, but several important new ideas are now being developed; no marked general increase in boiler pressure has been adopted; increase in size of units is conspicuous, as are very large power installations. Scotch boilers are slightly simplified and more dependable; great advance in reliability, efficiency, capacity and durability is noted in water tube boilers; the use of such boilers in merchant vessels is increasing, which permits a large saving in weight and space. Howden draft for merchant work is still favored. Important improvements have been made in feed heaters, feed pumps, and forced draft fans of steam and electric drive. The use of superheated steam is largely increasing and will probably continue, due to improved efficiency possibilities. Boiler-room communication, flue-gas analysis and ash and refuse handling have been largely perfected; boiler corrosion and boiler circulation are better understood and controlled; important advances have been made in methods of handling and burning oil.

A large opportunity is open to the various Governments and Classification Societies in connection with standardizing rules and requirements governing the construction and use of Marine Boilers and Boiler Room Equipment.

The writer wishes to express his grateful acknowledgments to the many friends in the engineering field, both in the United States and other countries, who have so materially assisted him with information, suggestions, data and drawings used in the preparation of this paper.*

* Credit is especially due to the following who have contributed information and assistance:

Rear Admiral R. S. Griffin, U. S. N., Messrs. J. E. Thornycroft, Harold E. Yarrow, William Wier, Augustin Normand and Company, J. & A.

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J. A. S. N. E.—Journal of the American Society of Naval Engineers.

Int. Mar. Eng.—International Marine Engineering.

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DISCUSSION

Mr. Geo. W. Dickie,† Mem. Soc. N. A. & M. E., thought the author devoted very small space to what, in his opinion, was the most important of present day boilers, the Scotch marine type. He quoted Lloyd's Register as authority that 88% of all ships registered are equipped with Scotch boilers, and believed it is an acknowledged fact that they are the most reliable boilers at sea today. Mr. Dickie.

Mr. Dickie said that the application of forced draft, especially with oil fuel, tends to reduce the size of boiler equipment. A boiler with divided furnaces presents difficulties when forced draft is used. The Howden system of forced draft excels in adaptability and convenience. It is not economical to burn more than about 300 lbs. of oil per hour in a single compartment of the Scotch boiler. He believed the Scotch boiler

† Naval Architect and Marine Engineer, San Francisco, Calif.

Mr. Dickie. of the future, for oil, would probably have 6, 8, or 9 furnaces. He said there were indications of advance in this direction and that such a boiler would be built when courage of the right kind was forthcoming. He considered the Scotch boiler further desirable because of the present tendency to divide ships into small compartments for purposes of safety. The large displacements of the Scotch boiler permitted less water to enter a compartment in case of collision. Mr. Dickie expressed the opinion that superheaters now on the market should be better adapted to the conditions of marine service. Simplicity should be an important consideration and simpler systems must be devised before general use becomes practicable. He stated that a new design of Scotch marine type of boiler giving superheated steam is under consideration.

Paper No. 211

THE DEVELOPMENT OF THE MARINE STEAM TURBINE.

By

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INTRODUCTORY.

The marine steam turbine is now generally applied for propulsion of the following types of vessels:

Naval Vessels	Battleships and Armored Cruisers, Protected Cruisers and Scouts, Destroyers.
Merchant Vessels	Fast Passenger Vessels, Moderately-powered Freighters, Yachts, to a limited extent.

The marine turbine is a development of the last two decades, and practically all the personnel having to do with the initiation of this development is still actively engaged in this field.

The first marine turbine was installed in the yacht "Turbina", built in 1894 by the Parsons Marine Steam Turbine Company. The first marine turbine installation in the United States was the Curtis turbine, in the yacht "Revolution", 1902-1903. The first United States naval vessels to have turbines were the Scout Cruisers "Chester" (Parsons) and "Salem" (Curtis), which were contracted for in 1905 and completed in 1908. The first United States Destroyers fitted with turbines (Parsons) were the "Smith", "Lamson", "Preston", "Flusser" and "Reid", contracted for in 1907 and completed in 1909, and the "Sterett" and "Perkins" (Curtis) contracted for in 1908 and completed in 1910.

Since the initial installations, the turbines have been used exclusively on destroyers and have been extensively employed

on battleships. England took the lead in using turbines and was followed by the United States, and since then turbines have been applied to a large extent in naval vessels of all the important navies, and are now employed in practically all capital vessels building.

The Parsons turbine was first developed in England and its application has now become universal.

The Curtis turbine was first developed in the United States, but in its adaptation to the marine field has been extensively developed as the A. E. G. turbine in Germany and as the Brown-Curtis turbine in England, while in the United States numerous turbines of this type have been built for the navies of the United States, Japan, Italy and Argentine.

The history of the development of the Parsons turbine has been fully dealt with in "The Evolution of the Parsons Steam Turbine", by Alexander Richardson, and the complete details of design and construction are given in the "Marine Steam Turbine", Southern, 3d Edition. The development and details of the A. E. G. turbine are fully dealt with in "Marine Steam Turbines", Bauer & Lasche.

As the length of this paper is limited, only general observations of the application of the turbine can be given.

TYPES OF TURBINES.

The number of types of marine turbines proposed and experimented with is almost countless. The really successful types are very few. The development of a successful marine turbine necessitates the work of years and requires the expenditure of large sums of money. The most generally successful marine turbine now in use represents the results of more than twenty years of application to the marine field. It required years of development to determine the details and proportions that would make it a thoroughly reliable machine.

The different makes, which have dealt mostly with the impulse type, have their differences based on details of construction and arrangement and are usually designed to secure advantages in space, simplicity, and in improving construction so as to avoid blading troubles.

The structural details of marine turbines and the conditions imposed are such that each detail must be properly developed by trial and experiment before it can be considered thoroughly reliable. Many of the details can not readily be calculated off-hand and, until the apparatus is actually tried in service, thorough reliance can not be placed upon new or novel designs.

Uncertain and unexpected things will happen with a marine turbine; even an old and tried design has its vagaries and unlooked for action, often not susceptible of a thoroughly plausible explanation.

GENERAL TYPES OF TURBINES.

There are two basic types of turbines that are met with in the marine field: the Impulse and the Reaction type; and lately a combination of the two, the Impulse-Reaction turbine, has been developed.

In the impulse turbine the steam is first expanded in a nozzle, or some equivalent of a nozzle, and the energy of the steam is converted into velocity, which velocity is transformed into mechanical work when the steam issuing from the nozzle impinges upon the rotating blades of the turbine. Figs. 1 and 2 show cross sections of marine turbines of the impulse type.

The impulse turbine has its form of blade designed for the impulse action of the steam, and owing to the fact that there is a high velocity impulse as the steam strikes the blades, the blading must be made, generally, of heavier construction than the blading of a reaction turbine.

Although the idea of the design is to have the expansion complete in the nozzles, actually some expansion also takes place as the steam passes between the moving blades.

In the reaction turbine the blading is such that the expansion of the steam takes place while passing through the moving blades, and the velocity of the steam is greater when leaving than when entering the blades. Stationary blades are provided, and they act to some extent as nozzles, but are mainly provided to collect and give proper direction to the flow of steam as it goes from one row of moving blades to another. Turbines of the pure reaction type are unknown prac-

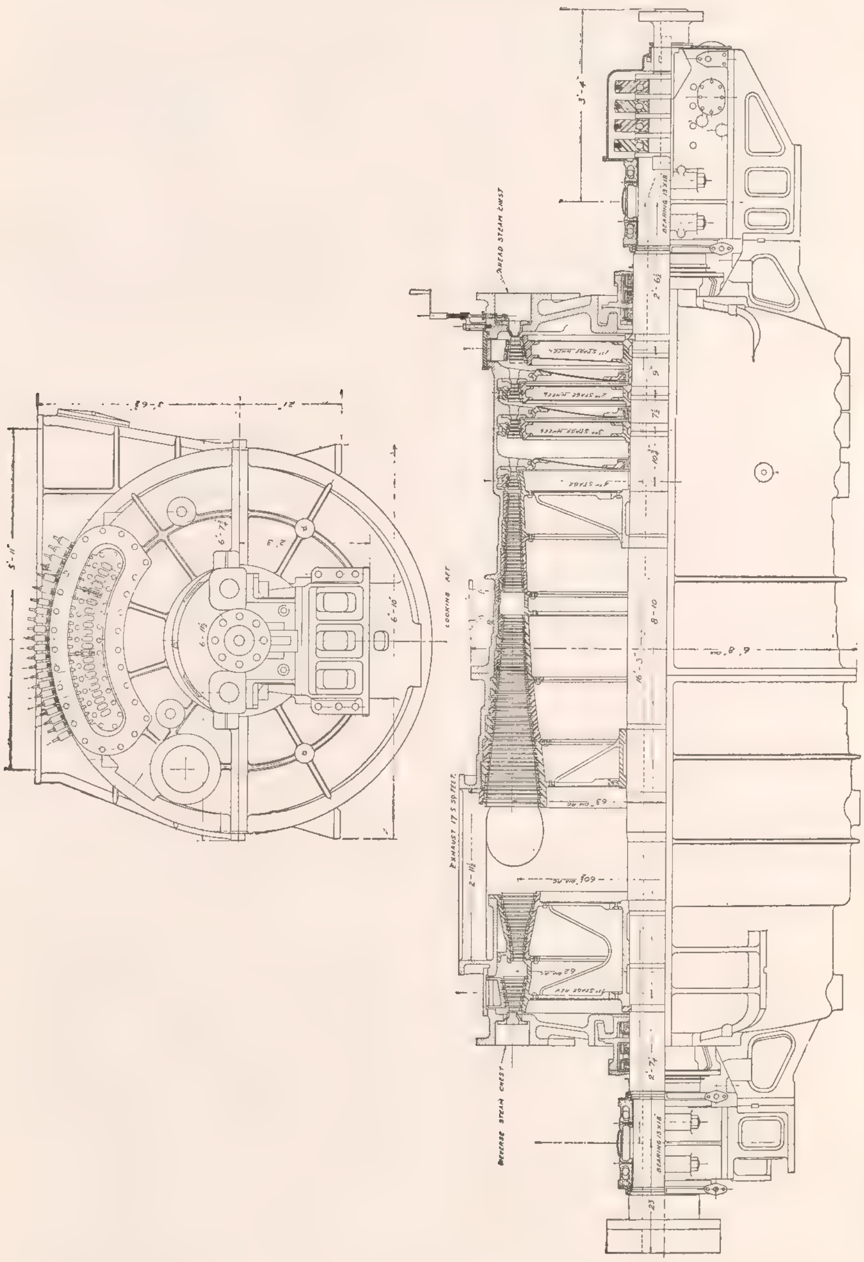


Fig. 1. Curtis Marine Turbine, U. S. Destroyers.

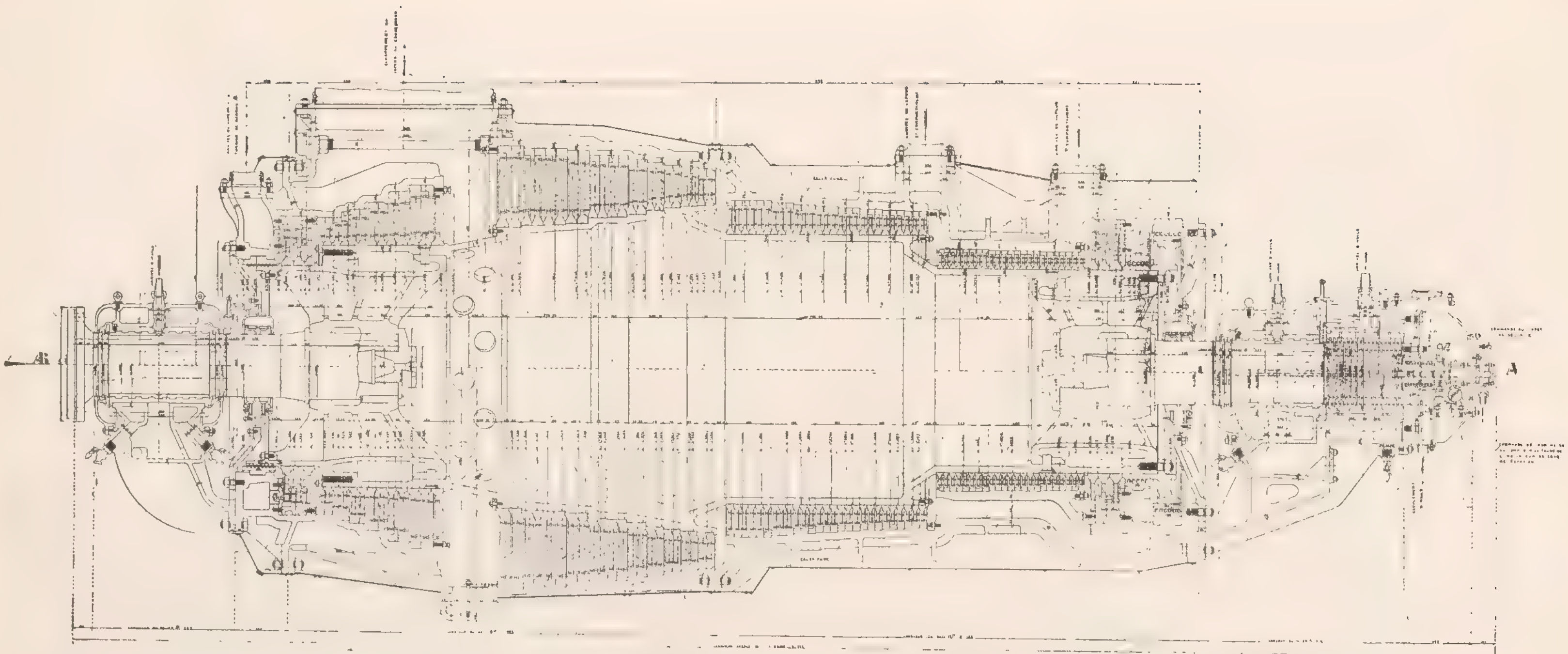


Fig. 2. Brequet Turbine, French Destroyer.

tically. In actual so-called reaction turbines about fifty per cent. of the expansion takes place in the moving blades and the other half in the fixed blades. The steam expands as it passes both through the fixed and the moving blades.

The distinction between impulse and reaction turbines is thus expressed by another author (Prof. J. H. Biles): "If the steam stream be free and not confined after leaving the guide blades, and if it impinges upon the moving blades, it is usually called an action or impulse turbine; but if the stream is confined within a vessel so that the pressure will cause the steam to fill the spaces and the streams will flow through the vanes imparting their energy without shock, the turbine is called a reaction turbine."

A further practical distinction may be made as between these two types as they have been developed for marine work:

(1) Reaction turbines in which the full expansion of steam does not take place in a turbine driving a single shaft, but where the steam, expanding from the inlet to the exhaust pressure, passes through several turbines arranged on several shafts. The Parsons turbine is the only successful turbine of this type that has been generally applied to marine work. It would not be practicable to build a turbine of this type of sufficient length to enable the relatively low speed to be obtained for driving one propeller shaft.

(2) Impulse turbines in which the complete expansion of steam, from inlet to exhaust pressure, occurs in a turbine on one shaft; sometimes known as one-shaft turbines. To this class belong the Curtis and its modifications, the Brown-Curtis in England and the A. E. G. turbine, developed in Germany; also the Rateau and Breguet turbines in France, the Zoelly in Germany and the United States, the Melms-Pfenninger and Schichau in Germany and Austria, and the Tosi turbine in Italy.

Of marine turbines of the impulse type, the A. E. G. turbine and the Brown-Curtis turbine may be said to have been fully developed in their mechanical details. The Curtis turbine other than the above, the Zoelly, Rateau, Breguet, Melms-Pfenninger, Schichau and Tosi turbines are, strictly speaking, still in a somewhat experimental stage.

TENDENCY TO APPROACH ONE TYPE OF DESIGN.

There has been a tendency in marine turbine design to use impulse blading for the high pressure end and reaction blading for the low pressure end of the expansion. The so-called impulse turbines now nearly all use the drum construction for the last stages.

This tendency has resulted in designs of turbines that are really a combination of the impulse and the reaction type. Examples of these are the Westinghouse-Parsons marine turbine and the Parsons turbine fitted with impulse stage in lieu of cruising turbines, as applied to many recent British naval vessels and referred to under the general heading of Cruising Turbines in this paper. See Fig. 7.

There are, however, vital differences in the character of construction, details of design, etc., between the turbines of different makers, especially as to the details of the blading and the methods of securing the blades and the rows of buckets in each stage. These are now, however, gradually coming to certain standard details and methods.

The Parsons turbine, after extensive experimentation, has adhered quite closely to certain details and arrangements that have been standardized, in which reaction or, as it is sometimes called, impulse-reaction blading, is used. The Parsons company has always recommended the use of reaction blading as being the more satisfactory and giving the better economy, and have only introduced the impulse stages used on some of their installations on account of the urgent desire of the British Admiralty to get away from the use of separate cruising turbines.

For shore work, in the United States, the impulse turbine, as represented by the Curtis units built by the General Electric Company, has shown itself generally somewhat more economical than the Parsons, and it may appear proper to expect the impulse turbine to approach the reaction type in economy for marine work when the design is so developed as to properly and certainly overcome mechanical defects.

The Curtis turbine generally employs impulse blading throughout.

The A. E. G. turbine in some designs has used reaction blading for the last stages of the L. P. This type is installed on the "Imperator".

RELATIVE ADVANTAGES.

Reaction Turbines.

This turbine is of simpler construction, is easier to construct and has been found to be cheaper to build, due in a large measure to the fact that the details are definitely known and experimentation has been practically left behind. On the other hand, this turbine requires a higher rotative speed to secure desirable economy and necessitates a division into a H. P. and L. P. casing.

Impulse Turbine.

The whole unit can be contained in one casing. Slower revolutions can be used. Less space is required. It was thought that less weight would be required, but this has not been found so in practice. The impulse turbine can vary the number of nozzles in use and can thereby improve the economy at low powers; but the reaction turbine with cruising turbines is generally more economical than the impulse type.

From the experience in the United States Navy thus far, the reaction turbine (Parsons) has given decidedly the best results in service.

BACKING AND MANEUVERING POWER.

One of the drawbacks of the turbine is its lack of reversibility, except by adding a special reversing turbine. While the backing power can be made quite satisfactory by the addition of powerful backing turbines, in no case is there secured the full backing effect that is possible with reciprocating engines. The first turbines for naval vessels were designed for about 20% backing power. This was found to be insufficient for proper maneuvering ability, and latterly, the backing power has been raised to 40% and 50%.

On the four-screw Parsons arrangement for battleships, backing turbines are placed on each shaft, a H. P. astern on one and a L. P. astern on the other shaft, on each side of the vessel.

On the three-shaft Parsons destroyer arrangement, back-

ing turbines are provided within each L. P. turbine on the wing shafts.

On the single-shaft turbines, backing turbines are provided in the after end of the turbine casing.

Turbine advocates have, by argument, attempted to prove that the turbine has superior advantages in handling, and have even gone so far as to state that in the turbine the power to stop or to reverse the direction of the ship is more effective than with piston engines. (Richardson, page 94.) This is faulty argument. In a reciprocating engine when the link is thrown over, the change in direction in movement is immediate. It can not be otherwise. In the turbine, the inertia of the moving parts has first to be overcome and the turbine must first be stopped before it begins to rotate in the opposite direction. It requires some appreciable time after steam is turned on the astern turbine before the turbine is actually going in the astern direction. Also the power that the turbine exerts is not effective until the inertia of the revolving mass has been built up; so, whereas in a reciprocating engine the steam pressure on the piston gives the backing power directly, the turbine does not give its proper backing power until it has been speeded up, and in starting in either direction the energy of the steam is first used in destroying the inertia in the revolving mass.

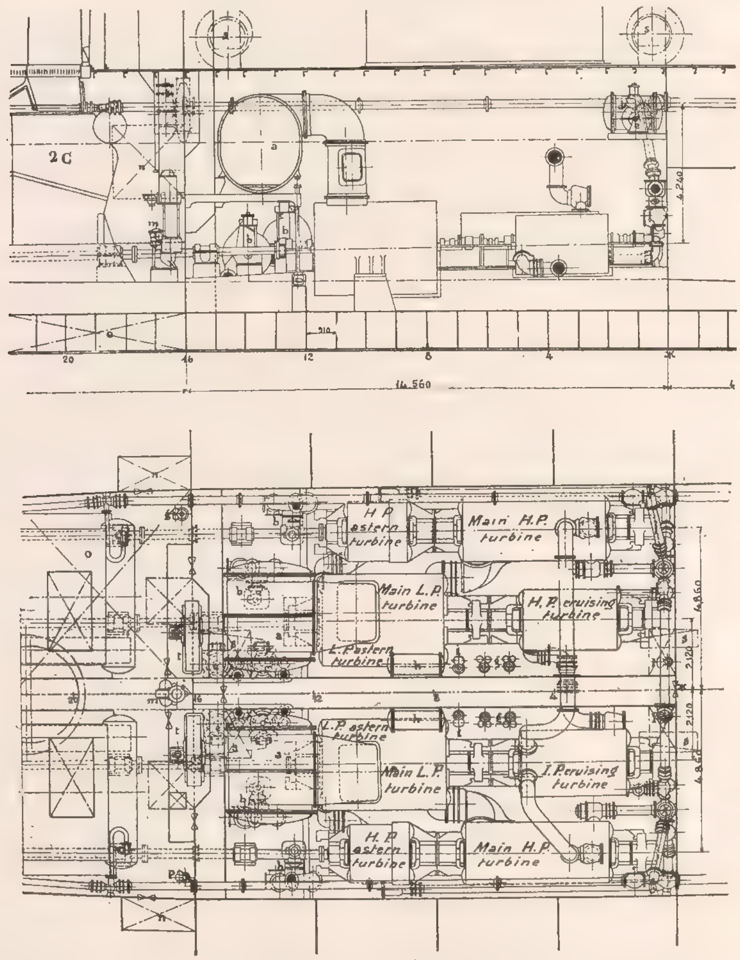
Though the backing power in a turbine installation is, or can be made, satisfactory, it is inherently less effective than that of a reciprocating engine. With the electric drive, however, full effective backing power is secured. No line of argument can alter the actual results that are demonstrated when turbine vessels and those with reciprocating engines are maneuvered together.

CRUISING TURBINES.

In order to secure better economy at low speeds, cruising turbines are fitted in connection with Parsons turbines on Naval vessels, and so-called cruising stages are provided on some of the single-shaft turbines.

With the Parsons installation, the cruising turbines usually consist of a H. P. and a L. P. cruising turbine. Typical arrangements of these cruising turbines are shown in Figs. 3a, 3b, and 4, for both the three-shaft and the four-shaft arrangement.

These cruising turbines are usually supplied on battleship installations and, in most cases, on destroyers, though late British destroyers do not have them, it being considered that



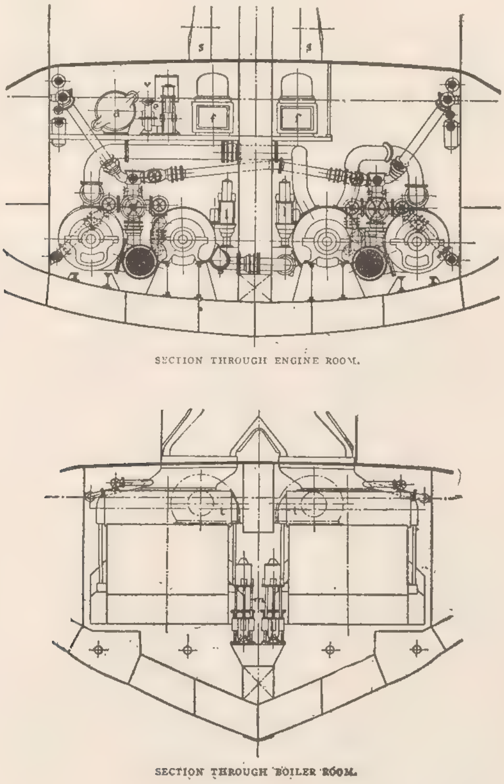
INBOARD PROFILE AND PLAN OF ENGINE ROOM.

J. A. S. N. E.

Fig. 3a. Parsons 4-Shaft Arrangement as Installed on Large Naval Vessels.

the destroyer is designed principally for high speed and that special economy at cruising speeds is not extremely essential. In the United States Navy there has always been a special effort to secure good economy at low speeds, both in battle-

ships and in destroyers, and in all turbine installations a cruising element of some kind has been fitted. On the United States Parsons battleships, "Utah", "Florida", "Wyoming" and



a—Main condensers.
b—Main circulating pumps.
c—Main air pumps.
d—Auxiliary condenser.
e—Aux. circulating and air pumps
f—Evaporators.
g—Oil pumps.
h—Oil coolers.
i—Oil cooler pumps.
l—Fire and bilge pumps.
m—Feed pumps.
n—Main feed tanks.
o—Reserve feed tanks.
p—Drain pumps.
s—Engine room aerating fans.
t—Forced-draft fans.
u—Ash hoists.
v—Aux. feed-water filter.

J. A. S. N. E.

Fig. 3b. Parsons 4-Shaft Arrangement as Installed on Large Naval Vessels.

"Arkansas", the arrangement shown on Figs. 3a and 3b is used, while on the later Parsons battleships, "Arizona" and "Idaho", geared cruising turbines are used.

On the early Parsons destroyers a H. P. and I. P. cruising

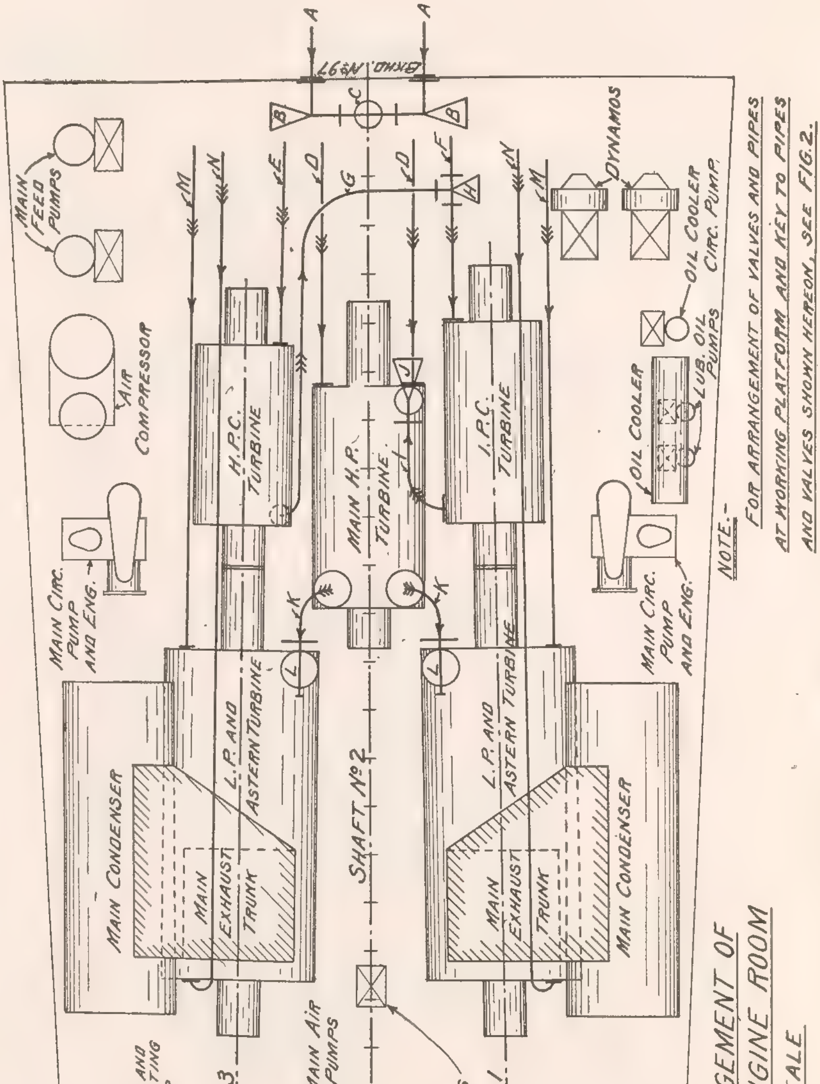


Fig. 4. Parsons 3-Shaft Arrangement as Used on U. S. Destroyers.

turbine were fitted. In later vessels a small cruising reciprocating engine is used, while in the latest vessels building, geared cruising turbines are employed, both in connection with the Parsons turbine and the Curtis turbine.

The use of these reciprocating cruising engines has resulted in securing a very large steaming radius, 6,000 miles, for the destroyers so fitted. An increase in economy of 20% at 15 knots and 50% at 10 knots, over use of main turbines direct, is secured by their presence. The gain in economy obtained by the use of cruising engines in lieu of cruising turbines is, however, not very material and probably does not amount to more than 10%.

The use of the I. P. cruising unit results in an increase of about 20% in economy over that of main turbines at speeds coming within the range of the I. P. cruising turbine; while the use of the H. P. cruising turbine adds about 12% to the cruising economy at the lower speeds.

On commercial vessels, cruising turbines are not fitted, since these vessels usually steam at somewhere near full power, so that the addition of special cruising units is not justified.

While the United States Navy has always had a leaning towards cruising elements and consequent economy at low speed, the British Navy has shown a tendency to get away from the use of cruising elements.

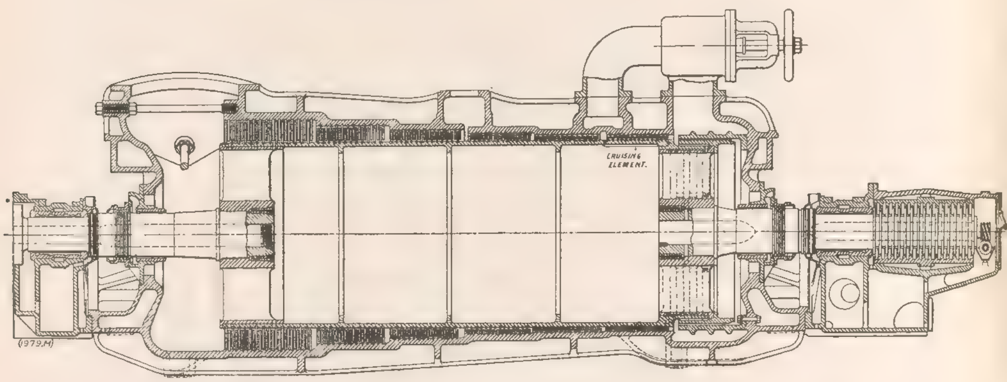
The English authorities express the opinion that although the cruising turbines are economical, there are certain inconveniences attending their use. As they are often not in use, they are likely to be neglected and will not receive the attention that they require. Most of the accidents to blading in Parsons installations have been in the cruising elements, for here the least clearances are used, while the turbines are subjected to the greatest variations in temperature.

The fitting of cruising turbines adds considerable weight; there are extra piping and several additional glands which may impair the vacuum. In view of the above, cruising turbines have not been fitted in recent British naval vessels, and the alternative of providing an additional stage or stages at the high pressure end of the H. P. turbine has obtained, so that when it is desired to run at lower fractions of power the full

pressure drop of the steam can be utilized. At higher powers steam from the boiler may be added through by-pass valves at intermediate stages. Thus, under working conditions, down to somewhat below half power quite satisfactory economy is secured.

A H. P. turbine of this kind is illustrated in Fig. 5.

At below half power this alternative does not give as good economy by 10% to 20%, as with the separate cruising turbines.



(Taken from Richardson, P. 151.)

Fig. 5. Section of Parsons High Pressure Turbine with Cruising Element.

THE COMBINATION OF IMPULSE STAGES AT HIGH PRESSURE END.

This is another alternative that is being applied in the English Navy in recent Parsons installations. In this case the volume of steam supplied to the turbine can be controlled by closing down as many of the admission nozzles in the impulse stage as may be required to suit the power developed. By means of this combination the pressure drop which produces expansion of the steam in the first stage is confined to the fixed jets and there is thus no loss by leakage. The impulse type of blading, with velocity corresponding, can in most cases be arranged to expand steam with fair efficiency to twice its volume in a single stage with blade speeds such as are possible in marine work. It has not been considered advisable to use more than one such stage before going over to the simpler,

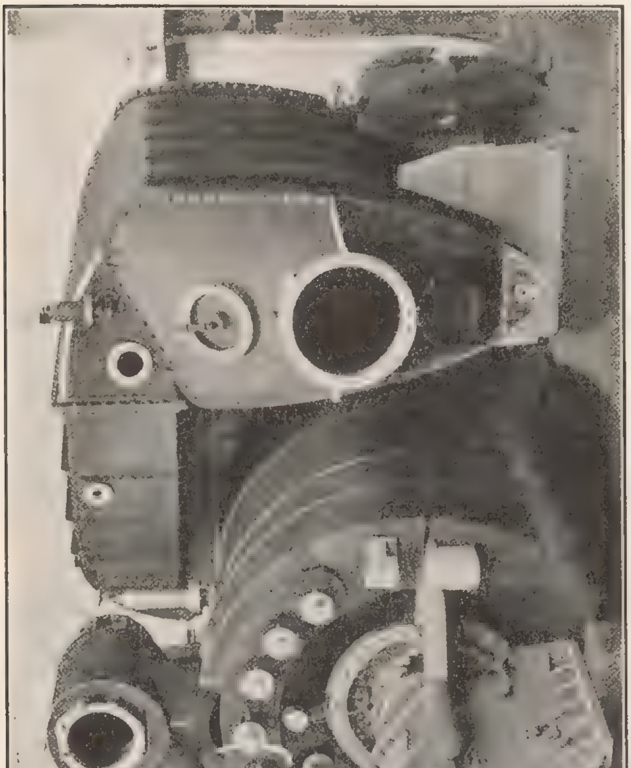


Fig. 6. Set of Parsons Turbines with HP. Impulse Stages.

J. A. S. N. E.

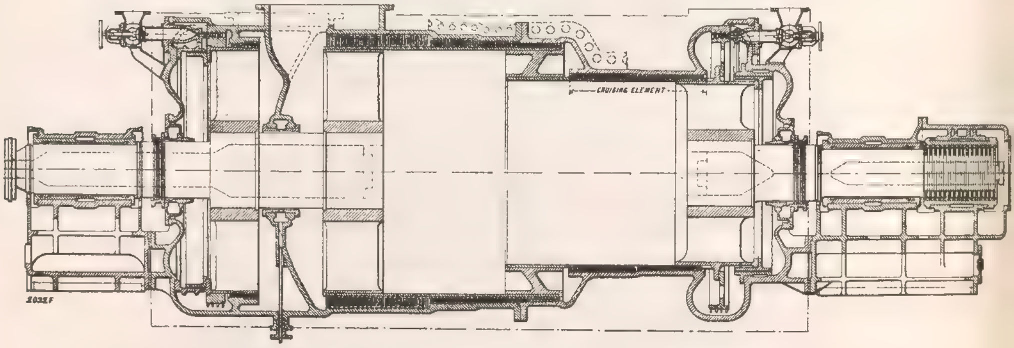
cheaper, and what is considered more efficient, drum construction. A turbine of this type is shown in Figs. 6 and 7.

While this type of installation appears to be in favor with the British Admiralty, it has not given as good economy as the regular cruising turbine arrangement, and the Parsons Company recommends cruising turbines in all cases where it is permissible to install them.

APPLICATIONS.

Direct Application.

The impulse type of turbine is usually applied in one complete unit for each shaft. The impulse-reaction turbine is divided into a H. P. and L. P. part, and these two parts normally



(Taken from Richardson, P. 154.)

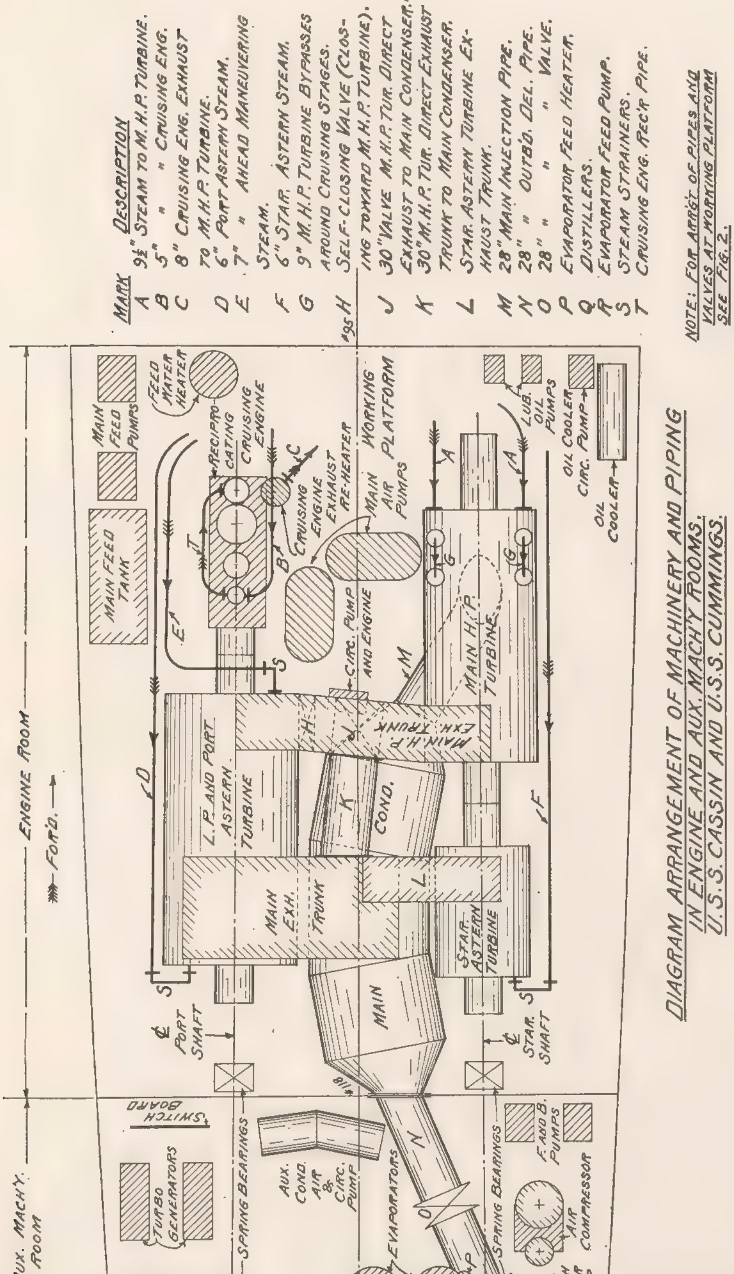
Fig. 7. Section of Parsons High-Pressure Ahead and Astern Turbines with Impulse Wheel at Initial End.

drive separate shafts. Backing turbines are fitted usually in the L. P. end, though on large naval vessels separate H. P. backing turbines are fitted on the shaft carrying the H. P. ahead turbine.

Arrangement of Turbines on Naval Vessels.

The application of Parsons turbines on large naval vessels is usually on four shafts; for destroyers, on three shafts.

In order to simplify the installation as much as possible and provide one large unit instead of two, the destroyers built by the Bath Iron Works, Bath, Maine, have a somewhat novel two-shaft arrangement shown in Fig. 8. This arrangement is now being used on destroyers building at other plants.



MARK DESCRIPTION
A 9½" STEAM TO M.H.P. TURBINE.
B 5" " " CRUISING ENG.
C 8" CRUISING ENG. EXHAUST TO M.H.P. TURBINE.
D 6" PORT ASTERN STEAM.
E 7" " AHEAD MANEUVERING STEAM.
F 6" STAR. ASTERN STEAM.
G 9" M.H.P. TURBINE BYPASSES AROUND CRUISING STAGES.
H SELF-CLOSING VALVE (CLOSING TOWARD M.H.P. TURBINE).
J 30" VALVE M.H.P. TUR. DIRECT EXHAUST TO MAIN CONDENSER.
K 30" M.H.P. TUR. DIRECT EXHAUST TRUNK TO MAIN CONDENSER.
L STAR. ASTERN TURBINE EXHAUST TRUNK.
M 28" MAIN INJECTION PIPE.
N 28" " OUTB'D. DEL. PIPE.
O 28" " " VALVE.
P EVAPORATOR FEED HEATER.
Q DISTILLERS.
R EVAPORATOR FEED PUMP.
S STEAM STRAINERS.
T CRUISING ENG. REC'R PIPE.
NOTE: FOR ARR'GT OF PIPES AND VALVES AT WORKING PLATFORM SEE FIG. 2.
AUX. MACHY. ROOM
ENGINE ROOM
FOR'D.
MAIN FEED PUMPS
FEED WATER HEATER
MAIN FEED TANK
RECIPRO-CATING CRUISING ENGINE
CRUISING ENGINE EXHAUST RE-HEATER
MAIN AIR PUMPS
WORKING PLATFORM
CIRC. PUMP AND ENGINE
MAIN H.P. EXH. TRUNK
MAIN H.P. TURBINE
LUB. OIL PUMPS
OIL COOLER CIRC. PUMP
OIL COOLER
L.P. AND PORT ASTERN TURBINE
COND.
MAIN EXH. TRUNK
STAR. ASTERN TURBINE
MAIN
PORT SHAFT
STAR. SHAFT
SWITCH BOARD
TURBO GENERATORS
SPRING BEARINGS
AUX. COND. AIR & CIRC. PUMP
F. AND B. PUMPS
AIR COMPRESSOR
EVAPORATORS
LATHE
DIST. FRESH WATER PUMP
DIAGRAM ARRANGEMENT OF MACHINERY AND PIPING IN ENGINE AND AUX. MACHY. ROOMS.
U.S.S. CASSIN AND U.S.S. CUMMINGS.

Fig. 8.

It will be seen that the H. P. turbine is on one shaft, while the L. P. is on the other. A special backing turbine is provided on the shaft carrying the H. P. turbine. A reciprocating cruising engine is provided. In this case, only one main condenser is required, which greatly simplifies the auxiliaries. This has proved a very satisfactory installation in service, and is believed to be the most economical destroyer installation, with the exception of those driven by geared turbines.

Impulse turbines on destroyers are installed in a two-shaft arrangement. On large vessels they are arranged on two, three and four shafts. In nearly all cases each turbine is complete in one casing, but in some recent installations ("Nevada" and "Pennsylvania") the casings of Curtis turbines are divided into a H. P. and a L. P. turbine. When four shafts are employed, the turbines are located in very much the same manner as with the conventional four-shaft arrangement so commonly met with in Parsons installations.

Arrangement of Turbines, Merchant Vessels.

The turbine installations for the merchant service, which in nearly all cases employ Parsons turbines, are usually the three-shaft arrangement,—one H. P. turbine exhausting into two L. P. turbines, with backing turbines in the L. P. casings.

In a few cases twin-screw arrangements have been used, with the H. P. turbine on one shaft and the L. P. on the other. With a view to improving the economy, four-shaft arrangements having a H. P., I. P. and two L. P. turbines, have been adopted on some recent vessels, and this arrangement enables better economy to be obtained at lower speeds.

A few impulse turbines have been used in the merchant service. These are mostly two-shaft installations. The "Imperator" has a four-shaft arrangement of this kind, using Curtis-A. E. G. Vulcan turbines.

Combination Reciprocating Engine and Turbine.

In this system one or more reciprocating engines are used in combination with one or more L. P. turbines. The steam is used first in the reciprocating engine, and the exhaust from this is led to the turbine. By means of this system special advantages in economy are obtained. The reciprocating engine is more economical in steam consumption than is the H. P. end

of a turbine, while the L. P. end of a turbine is more economical than the cylinder of an engine. This latter is due chiefly to the fact that in the turbine a good vacuum can be much more efficiently utilized. Consequently, in the combination each type of engine operates for that portion of the cycle for which it is best adapted, and the final economical result is one materially better than either the reciprocating engine alone or the turbine alone.

There are other incidental advantages over the direct turbine drive. The backing power is supplied by the reciprocating engine, which is more effective than the backing turbine, and the L. P. turbine used is built without having the complicating feature of a backing turbine.

The combination enables superheated steam to be used, which is considered inadvisable in connection with reaction turbines.

This combination has been successfully applied to a considerable number of White Star liners, the most recent and largest installation being that on the "Brittanic".

A number of French merchant vessels, among them the S.S. "Rochambeau", use the combination. On all these vessels a fuel economy is secured better than with installations employing direct turbine drive or reciprocating engines.

A modification of this system has been employed on some recent United States, and on some French and Italian, destroyers. (Fig. 9.)

The engines are designed to give the vessels a speed of about 16 knots when working in series with the turbines, and above this speed the turbines alone are used. (Referred to under "Cruising Turbines".)

REDUCTION SYSTEMS.

The Electric Drive, Hydraulic Transmitter and Reduction Gearing have been put forward in order to combine a high speed turbine with a slow-running propeller and so obtain the greatest efficiency of each.

Electric Drive.

The electric drive has been installed on two sea-going vessels, the U. S. Collier "Jupiter" (Curtis turbines) (Fig. 10) and the British ship "Tynemouth" (Diesel).

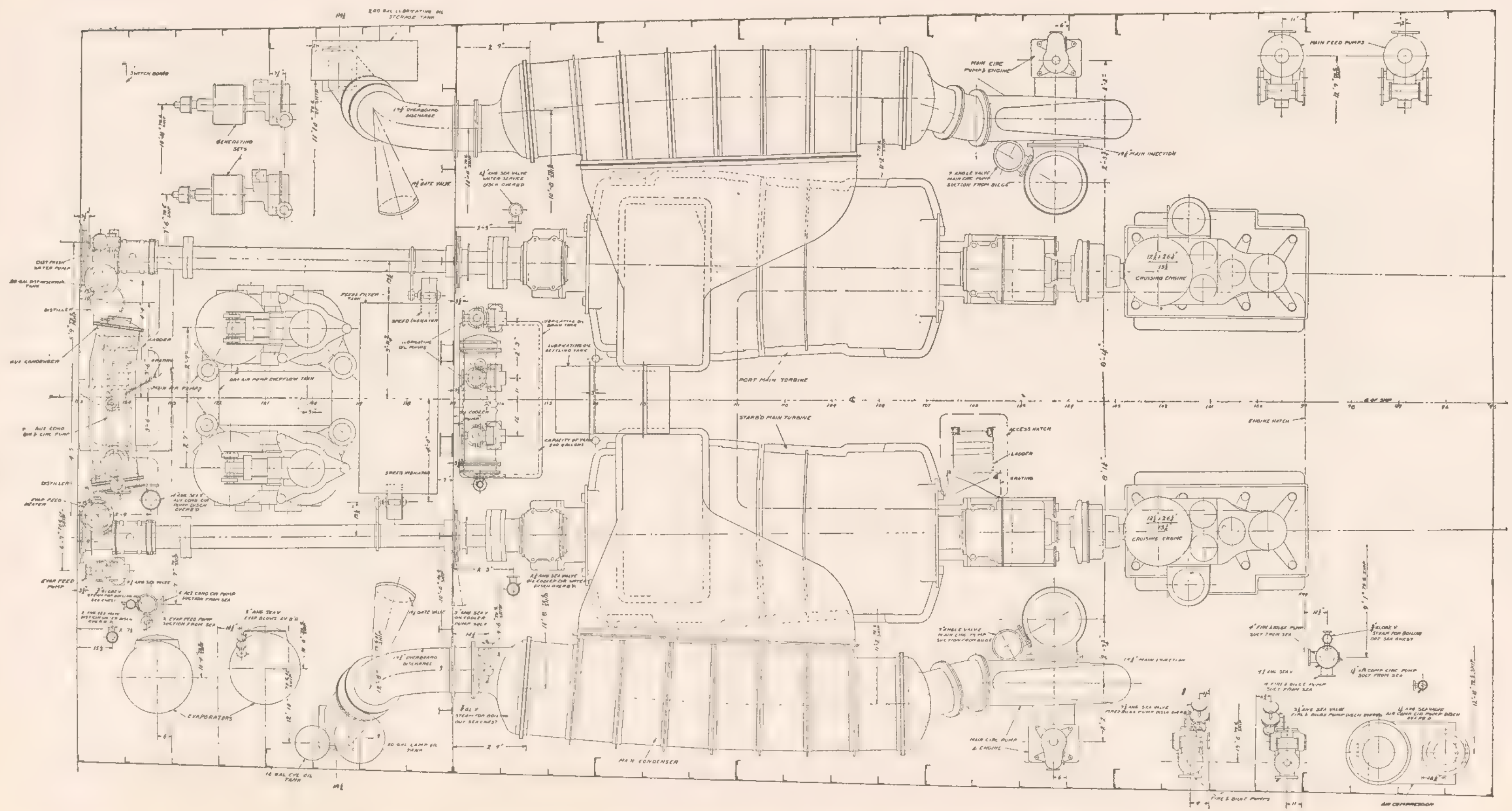


Fig. 9. Curtis Turbines with Reciprocating Cruising Engines, U. S. Destroyers.

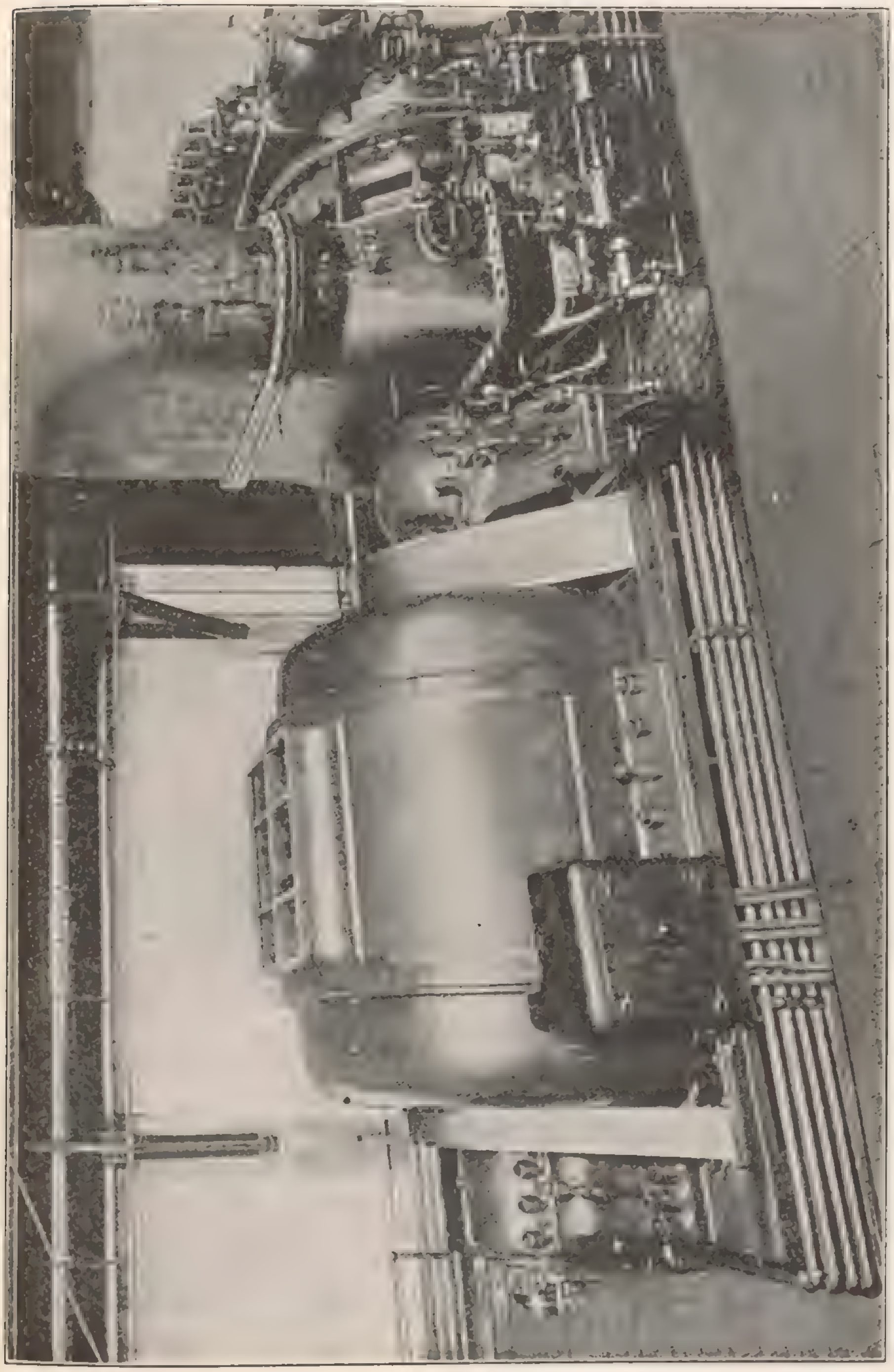


Fig. 10. Generating Unit, U. S. Collier "Jupiter." G. E. Electric Drive.

In the electric drive a high-speed turbine or a Diesel engine drives a generator, and the current there developed drives alternating-current motors placed upon the propeller shafts.

The efficiency of the transmission is 91-92%. This system has greater flexibility than the gear, can obtain a better comparative economy at cruising speeds, and has special advantages in the matter of handling and facility for overhaul while underway at reduced speed.

The electric drive is considerably heavier than gearing and requires more space for installation. It is, however, considerably lighter than the direct drive and for varying speeds and at cruising speeds will probably be as economical as the gear.

Electric drive apparatus built by the General Electric Company will be installed in the U. S. Battleship "California" now building at the Navy Yard, New York.

Föttinger Hydraulic Transmitter.

This apparatus employs a high-speed turbo-centrifugal pump with a water turbine designed for a lower speed of revolution. The pump is coupled direct to the steam turbine, and the water turbine to the propeller shaft. The pump and water turbine are placed in one casing and so designed that frictional and eddy losses are reduced to a minimum.

The transmission efficiency of this transformer is about 90 percent, though its promoters claim that if the heat generated in the water is used for feed heating, the final efficiency is about 92 percent. The speed ratio is usually about 6 to 1, though somewhat larger ratios can be employed.

This gear, like the electric drive, has the advantage of being able to employ a non-reversible turbine. About 85 percent of full go-ahead power can be secured for backing.

In a single unit, powers up to 10,000 have been transmitted; and this gear is being installed on a German vessel in which 23,000 shaft hp. are to be handled on two shafts.

The hydraulic transmitter accomplishes some saving of weight over the direct turbine drive. Apparently, it will secure about the same economy as the electric drive, but does not give as great flexibility.

Gearing.

A considerable amount of experience has been obtained, and this has so far been successful as far as the gear is concerned.

Most of the gear installations have been those of Parsons design, which has been employed on numerous British passenger vessels, notably, the "Normannia", "Hantonia" and "City of Paris". It has also been employed in some British destroyers and cruisers.

Westinghouse gearing, which is hydraulically balanced, was used on the U. S. Collier "Neptune" which has just been placed in commission with the latest type of Westinghouse gearing. Gearing is being used with Parsons turbines on the U. S. Destroyer "Wadsworth", the Submarine Tender "Bushnell" and the Destroyer Tender "Melville", now building, and is being extensively used in connection with geared cruising turbines on late battleships and destroyers.

The loss by gear transmission is small, not over 2%, and the wear on the teeth is unappreciable. Some objection has been raised to the noise, but this is not very material. The gear ratio used varies between 5 to 1 and 20 to 1.

The use of gear saves considerable weight and secures 10-15 percent better economy than the direct drive. Gearing is especially suitable for merchant vessels of low speed and moderate power and for destroyers and fast cruisers. As yet it has not actually been installed on any capital naval vessels.

Gearing has been employed in several British destroyers that have seen service during the present European war.

ADVANTAGES THAT THE APPLICATION OF THE MARINE TURBINE HAS SECURED.

For Commercial Vessels.

For high-powered vessels, a perceptible gain in economy has been secured, also a reduction in cost of installation and saving in space in special instances, particularly where very large powers are used. For low- or moderately-powered vessels the directly driven turbine offers no advantages in over-all economy, space or cost over a well designed, up-to-date reciprocating engine.

Vibration is avoided, and this is a special point for consideration in the case of passenger vessels; and also, owing to lack of vibration, the hull structure could be built somewhat lighter.

The use of oil for internal lubrication is avoided and this results in much better conditions for the boiler plant. This is a very important advantage and one seldom mentioned.

The operating conditions are considerably improved and the machinery can be more easily maintained in a state of repair. When blading stripping is avoided, the cost of repairs is considerably reduced from that with reciprocating engines.

For Naval Vessels.

Besides the advantages that are mentioned above, the following apply particularly to naval vessels.

Greater flexibility in changing from one speed to another is secured. Adjustments to suit conditions at different speeds are more readily made.

The ability to maintain full speed continuously is better, there being less danger of bearings heating, joints blowing or other small derangement which may make it necessary to slow down.

In the case of very high-powered vessels, such as destroyers and scouts, the machinery can be placed in a more confined space.

Better economy at full speed is obtained, but this advantage is not very great on large vessels, though quite material on destroyers.

There is greater ease in attendance and, as a consequence, the engine room personnel can be reduced to some extent.

The absence of vibration makes a steadier gun platform, enables a lighter hull construction to be used and improves the habitability. This is the important military advantage that the turbine has.

For high-powered naval vessels the cost of building is less, but though the cost of repairs should be less, the presence of a large amount of blading troubles has caused the repair bills with the turbine installation to be fully as great and, in many cases, greater than with reciprocating engines.

PRESENT AND FUTURE APPLICATIONS OF THE MARINE TURBINE.

At present, the turbine installations being made, proposed, and those that are probable in the future, may be enumerated as follows:

For Naval Vessels.

Capital Ships. Directly coupled turbines (1) without cruising turbines, (2) with cruising turbines directly coupled, (3) with geared cruising turbines, (4) electric drive, (5) geared turbines.

The combination of reciprocating engines in connection with L .P. turbines has been proposed, but not actually put into practice.

For the future, there is a strong possibility of the extensive use of geared turbines and the electric drive and, also, a more limited use of the hydraulic transmitter. These new applications will result in better economy (10-15%), less space being required, and less cost.

Destroyers and Scouts. Directly connected turbines (1) without cruising turbines, (2) with directly connected cruising turbines, (3) with reciprocating cruising engines, (4) with geared cruising turbines.

A few installations of geared turbines for main engines are being built, both in the United States and in England, and in the latter country some have been completed.

In the future, geared turbines will probably be used to a considerable extent, with some possibility of the electric drive.

For Commercial Vessels.

Fast Passenger Vessels and Yachts. (1) Directly connected turbines, (2) geared turbines, (3) combination of reciprocating engines and L. P. turbines.

The combination secures better economy than the directly connected turbine and about the same as the geared turbine, but it will weigh more and require greater space than the geared turbine.

In the future, the geared turbine, the electric drive and the hydraulic transmitter may be expected, with the geared turbine having the lead.

Slow and Moderate-Powered Merchant Vessels. The geared turbine is the only turbine drive actually being applied in this field. The combination is proposed, but not for small powers.

In the future, the geared turbine and the electric drive may be expected to divide this field with the oil and the steam reciprocating engine.

There is a great variety of marine craft for which the installation of turbines is not well adapted; among these may be mentioned vessels of low powers, below 1000 hp., tugs, ferry boats, dredges, and all craft that stop frequently and whose work is intermittent and at low power for any considerable part of the time.

ECONOMY.

The marine turbine has, in most engineering literature, been credited with having accomplished a considerable saving in fuel consumption and in weight and space as compared with the reciprocating engine. This claim is not generally borne out in practice and the advantage of the turbine in the matter of economy is shown only in very high-powered vessels, such as destroyers and very fast passenger vessels. The turbine shows a better consumption of water or fuel per horsepower, but when the propeller efficiencies are considered there is no material gain in economy over a thoroughly well designed quadruple, or even triple, expansion engine.

It has been a fact that in most cases where a comparison between a turbine and a reciprocating engine has been made, the reciprocating engine selected has been one that is really not up to the best reciprocating engine practice. Even in the comparison of the geared turbine on the "Cairnross" with the reciprocating engine of the "Cairngowan", the engine of the "Cairngowan" can not be considered as representing the best type of reciprocating engine as far as economy is concerned.

The saving of space has not been material, and on large naval vessels the turbines actually call for more space than is required by the reciprocating engine.

The advantages of the direct-connected turbine for the vessels on which it has been adopted lies chiefly in other fields than fuel economy or reduction in space.

LACK OF ECONOMY AT LOW SPEEDS.

A marine turbine is not economical at low powers. This is a serious disadvantage and one that has arrested the progress of installations on men-of-war to some extent. It is due directly to this fact that the United States Navy went back to reciprocating engines in the battleships "New York", "Texas", and "Oklahoma". By the introduction of cruising turbines, the turbines may secure a fair economy at low powers, but even with the best cruising turbines the well designed reciprocating engine using superheated steam has an advantage of 5 to 8% at 12 knots speed.

By the use of geared turbines this lack of economy at low powers will be reduced to some extent, but even then at low speeds the well designed reciprocating engine will be about as economical.

The electric drive, using two or more generators, and the combination of reciprocating engines and L. P. turbines, will probably give better economy at low speeds than will the reciprocating engine.

The direct-connected turbine can not be successfully applied to a vessel that operates for any considerable part of the time at low speed. The turbine is suited for high-speed and constant-speed conditions. Hence, many of those who have earned the reputation of being non-progressive by not adopting turbines for moderate-powered vessels have really been wise in their conservative action.

SUPERHEAT.

Superheat is not usually employed with Parsons turbines, and the reason for this is that, on account of the small clearances, the wide variation of temperature that may be present when superheat is used may cause distortion, which may result in blading troubles. It is also feared that the higher temperature may have a deleterious effect upon the material of the blades. Superheat is, however, used in some cases with Parsons turbines with success. Superheat is usually used where the impulse type of blading is used. The impulse blading has larger tip clearances, and, hence, a greater variation of temperature is not considered especially dangerous.

Superheat adds considerably to the economy and the possibility of its employment is one of the principal points of advantage of the impulse type of blading.

DIFFICULTIES EXPERIENCED.

Turbine installations have by no means been free from mishaps, and blade stripping is not an infrequent occurrence. In Parsons turbines, blade stripping is usually caused by a distortion of casing or rotor. In the naval installations, most of the cases of blade stripping have been in the cruising elements, where the clearances are the smallest, and which turbines receive the roughest handling.

Parsons Turbines.

Difficulties with thrust bearings have been encountered in cases where a condition of unbalance, of any considerable amount, is produced between the steam thrust and the propeller thrust.

Curtis Turbine and Zoelly Turbine.

In the Curtis and Zoelly turbines there has been considerable difficulty due to the inability to allow properly for the longitudinal clearance between the stages under different conditions of power. Whereas, the clearances may be proper at low powers, at high powers movements take place that cause a rubbing of the sides of blading and a consequent wearing away of the shrouding, resulting finally in the blading being ripped out.

Considerable blading difficulties have also been met with in Curtis turbines in the United States, due to blading being too weak to take the steam thrust placed upon it. The latest designs have remedied this defect.

Rusting of Interiors.

Rusting of interiors of turbines has also been experienced. This is due to the accumulation of water and access of air. If the turbines are kept dry by operating the air pump for a short period several times a week, the accumulation of water is avoided. The drainage of the turbine is a very important matter and should be carefully looked out for. Considerable rusting and corrosion have at times been due to the fact that parts of turbines have been left without drains.

Various types of paints have been used for protecting interiors of turbines from corrosion but none yet tried appear to be very effective. The best means so far discovered is to keep the turbines dry.

INCIDENTAL INFLUENCES.

The introduction of the marine turbine has had two very material effects upon marine machinery in the development of methods and apparatus for securing (1) better vacuum, (2) better efficiency for high-speed propellers.

Vacuum.

With the reciprocating engine, though a better vacuum is important and desirable, the increase in economy incident thereto is not nearly as great as it is with the turbine, and, in fact, it is chiefly due to this ability to use a high vacuum that the good economy of the turbine can be realized. Therefore, with the advent of the turbine, special means for securing high vacua were introduced into marine practice. About the first of these devices was the Parsons augmenter, and almost at the same time the dry vacuum apparatus, in which the air and water are taken separately from the condenser, was introduced. The two systems most generally used now are the augmenter and the dual air pump, though numerous other special types of air pumps are successfully employed.

Condenser design has also received more scientific attention, and special types of condensers built on thoroughly scientific principles are now more generally installed.

Propeller Design.

The turbine is a high speed machine, hence it is desirable to have high propeller speed, which detracts from propeller efficiency; but the need for using relatively high speeds has caused special investigation into propeller design to be made, with the result that propellers on destroyers operate at 900 revolutions per minute with 60% efficiency.

DISCUSSION

Mr. Tatsuo Furuichi* objected to the statement by the author that the electric drive is considerably heavier than gearing. He contended that the electric drive is lighter and requires less space than the geared drive. **Mr. Furuichi.**

*Navy Department, Tokyo, Japan.

Mr. Furuichi. He quoted estimates on the weight of electric drives for the battleship "California" by the General Electric Company of 700 tons and the Westinghouse Company of 500 tons, as compared to the 900-ton proposed geared installation. He said that direct drive could be made as light or lighter than geared drive for destroyers or cruisers.

Lieut. Cox. **Lieut. O. L. Cox, U. S. N.,†** wrote that the author's statement relative to economy at low powers by varying the number of nozzles in use with the impulse turbine is probably true in those cases where the turbine runs at constant speed and varying load, as in turbo-generators. But in case the speed of the turbine varies with the load, there is practically no difference in economy whether all nozzles and low steam-chest pressure are used, or few nozzles and high steam-chest pressure; the advantage, if any, being with the former. He stated that this is due to the fact that at low powers with few nozzles and high steam-chest pressure, part of the expansion takes place after the steam has left the nozzle, causing eddies in the steam jet and consequent loss in efficiency at low powers. All stages, except the first, are working practically under the same steam conditions, irrespective of the manner in which steam is admitted in the first stage; therefore, any increase in economy at low powers must be made in the first stage. In any expansion nozzle with a given expansion ratio, the ratio between the initial and final absolute pressure is constant. For example, for a nozzle designed to expand from an initial pressure of 300 lbs. per sq. in. absolute to the final pressure of 100 lbs. per sq. in. absolute, the initial pressure should always be approximately three times the final pressure, in order that the nozzles may be working under the best conditions. If the final pressure is 25 lbs. absolute, then the initial pressure should be 75 lbs. absolute. In order to obtain the necessary control of pressures, it may be necessary to use a few individual nozzles, but owing to the trouble required to keep them from leaking, a better way is to divide the steam chest into two parts, with a steam pipe and throttle valve for each, with two or three overload nozzles in each chest controlled by individual valves,—either this method or the one using group control (four or five nozzles per valve), as used in all late designs for impulse turbines where the speed of the turbine has to vary with the load. Mr. Cox thought the statement that the backing power of turbine-driven vessels is 40% to 50%, not quite clear as to its exact meaning. He asked if it meant that with the boiler power in use it is possible to develop that percentage of the ahead power when backing? He said that ships are seldom run without a reserve in boiler power and, consequently, boilers can be forced quickly for backing purposes. He asked if the power developed under these conditions is that to which the author refers. In his opinion, what was meant is that when going astern and using the same amount of steam as when going ahead, the power developed is from 40% to 50% of that developed ahead. Referring to advantages, Mr. Cox suggested that one material advantage of a turbine installation is that it can be so arranged as to partially bal-

† Bureau of Steam Engineering, U. S. Navy, Washington, D. C.

ance the propeller thrust at all speeds. This reduces the size and weight of the thrust bearings, and also puts less stress on the bearing foundations. It is the practice to design the turbine so that the steam thrust on the drum head practically balances the propeller thrust, when developing about 85 to 90% full power. At higher powers the steam thrust is greater than the propeller thrust, and at low, the reverse is the case. Lieut. Cox.

Mr. Anderson.

Mr. Ernest H. B. Anderson,* Mem. Soc. N. A. & M. E., wrote that he considered that the author laid insufficient stress on the fact that the trend of practically all marine-turbine design is to adopt the drum construction for the rotor, and thus follow closely the pioneer work of that great inventor and designer, Sir Charles A. Parsons.

He stated that in all the so-called impulse turbines, the greater portion of the turbine is now made with a drum construction, that the illustrations shown in the paper clearly demonstrate this feature. In the largest installations of this type, the turbines are being split up in series and drive independent shafts, again following the standard practice adopted from the earliest Parsons turbine installations. This applies to the machinery installation of the ''Imperator'', with A. E. G. turbines; U. S. S. ''Pennsylvania'', with Curtis turbines; and H. M. S. ''Tiger'', with Brown-Curtis turbines.

He said that at the present time there are no regular impulse-wheel turbines being built, as practice has shown that this type of turbine, having a large number of wheel stages separated by diaphragms, cannot be built successfully in the large sizes required for high-power naval vessels, and all turbines of this type have one or at the most two wheel stages, whilst the remainder of the turbine is built with drum construction.

He found it somewhat difficult to believe the statement of the author that Curtis turbine units built by the General Electric Co. for shore work are somewhat more economical than the Parsons, and of interest to note that Curtis turbine design has been revolutionized quite recently, whereas Parsons impulse-reaction turbines continue to set a standard, the blading of a number of the largest and latest turbo-generators at work being of the impulse-reaction type throughout.

He stated that astern or backing turbines are being made larger for all the latest installations, with the result that there is a marked improvement in this respect and characterized the statement that full backing power is obtained with the electric drive as more or less of a fallacy.

He said that when manoeuvring, the U. S. S. ''Jupiter'' has only 20% full-ahead power available for backing, giving as authority for this statement Lieutenant S. M. Robinson's paper in The Journal of the American Society of Naval Engineers, May, 1914, pages 340 and 341.

With reference to electric drive, Mr. Anderson was of the opinion that ship propulsion by electric motors is still very much in the nature of an experiment.

*Technical Representative, Parsons Marine Steam Turbine Co., New York, N. Y.

Mr. Anderson. He believed the success of the installation in the U. S. S. "Jupiter", so far as it goes, has clearly shown that such a method is practicable, but that it has reached a stage where an installation of this type can be taken charge of and operated successfully by the ordinary marine engineer, either naval or in the merchant service, he considered open to question.

The success of the "Jupiter" machinery has been chiefly due, he thought, to its being handled entirely by a naval crew, whereas all other ships of this class are in charge of civilians. He did not think the "Jupiter" machinery had shown any remarkable economy, the trial results bearing this out fully; the water consumption data given for "turbine steam consumption" being merely an approximation and not a result obtained by measuring the steam used in tanks. (Journal of American Society of Naval Engineers, May, 1914, page 353.) In the matter of the coal consumed during the 48-hour trial at full speed, he said the U. S. S. "Cyclops" made a better showing, beating the performance of the "Jupiter" by about 8½%.

Regarding the electrical installation proposed for the battleship "California", Mr. Anderson stated that the figures published when the bids for this installation were opened showed that the weights of the turbo-electric propelling apparatus were just equal to the weights of a four-shaft direct-drive turbine installation.

He said that mechanical reduction gearing is making rapid progress in all classes of vessels and there are now upwards of 1,000,000 shaft horsepower of Parson's geared-turbine installations in service and under construction. Practically all the latest high-power direct-drive turbine installations in fast cruisers and battleships are fitted with geared cruising turbines arranged with a clutch so that these units can be cut out entirely when the vessel is going at full speed. This also applies to destroyer machinery, where there are now in service a large number of installations having geared cruising turbines.

He expressed the opinion that a geared-turbine installation would be most successful in a battleship of large power and in no way could such a design be considered in the nature of an experiment. The weights of the propelling engines would be approximately one half of direct-drive turbines, or the estimated figures given for turbo-electric propelling units. Moreover, independent control of each shaft would be a leading factor and the chances of any breakdown crippling such a vessel are negligible.

He said the main advantages were saving in weight, space and cost, and increased economy, varying from 10% upwards, over all existing methods of propulsion.

In connection with the comparison of the "Cairnross" and "Cairngowan", he believed the author did not realize that the engine of the latter is of the highest grade and workmanship, that it was built by a firm who has had a very great experience in this class of work and it does represent a high grade of engine in this class of vessel. It does not

represent Admiralty or Naval practice in any way, and the comparison made was between practically two identical vessels of the same class. Mr. Anderson.

Mr. Anderson contended that the introduction of turbine machinery for marine propulsion has made the reciprocating-engine designers improve their work to a very marked degree, the U. S. Battleships, ''New York'', ''Texas'' and ''Oklahoma'' embodying in their machinery installations exceptionally fine design and workmanship, probably giving the maximum economy attainable with this type of engine.

He considered this type of engine not suitable for the high powers required to give the desired speed of the large battleships and battle cruisers.

He said superheat can be and is being used with many Parson's turbines, that objections to the use of superheat apply to reciprocating engines as well as to other types of marine engines. The Navy Department adopted superheat in the battleships ''Michigan'' and ''South Carolina'', but not in the later vessels.

To successfully use superheat steam with Parson's turbines, the blading material, where subjected to the high temperature steam, requires to be made of copper and not of brass, and it is advisable to make the high-pressure turbine casing of cast steel. This last factor has retarded the use of superheat steam in marine turbines, due to the difficulty of obtaining sound castings.

Troubles with turbine machinery are becoming more and more rare. The men operating the turbines are now entirely familiar with the interior of the machines and understand their peculiarities.

Much more attention is also being paid to drying out the interior surfaces and in large installations access to the interior is readily obtained, with the result that any corrosion troubles can be traced to sheer carelessness on the part of the operating staff.

Paper No. 212

THE APPLICATION OF THE STEAM TURBINE TO MARINE PROPULSION.

By

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The steam turbine had passed its experimental stage before any effort was made towards its application to the propulsion of vessels, having been previously developed into an efficient motor for driving electrical generators. In this class of work high rotative speeds were desirable and the rapidity with which the turbine supplanted the reciprocating engine was not surprising.

The marked success of the little "Turbina" built by the Hon. Sir Charles A. Parsons in 1894 demonstrated the possibilities of the high-speed turbine-driven propeller so well that a few years later the British Admiralty ordered the 31-knot destroyer "Viper" equipped with turbines built by the Parsons Company. A second destroyer, the "Cobra", was also equipped with turbines by the same firm, followed by the cruiser "Amethyst". Each succeeding year marked its further application as a means of propulsion of vessels of all classes.

The Curtis impulse turbine was first installed experimentally in the yacht "Revolution" in 1903 and the second installation was made in the 15½-knot 10,000-ton merchant ship "Creole" in 1904. In the latter ship there could hardly have been selected a more unsuitable type of vessel for direct drive, and the turbines were eventually replaced by reciprocating engines. The impulse turbine has since been developed into a highly efficient machine and some of the later types are capable of equalling the performance of the reaction turbine, although the great majority of marine-turbine installations are of the latter type.

In applying the turbine to marine propulsion, the greatest

difficulty lay in adapting the propeller to a speed of rotation consistent with turbine efficiency. Prior to the advent of the turbine, the propeller revolutions were from 70 to 100 per minute for the average fast merchant vessel, from 100 to 130 per minute for the larger cruisers and battleships, and from 200 to 450 per minute for the smaller high-speed vessels and destroyers.

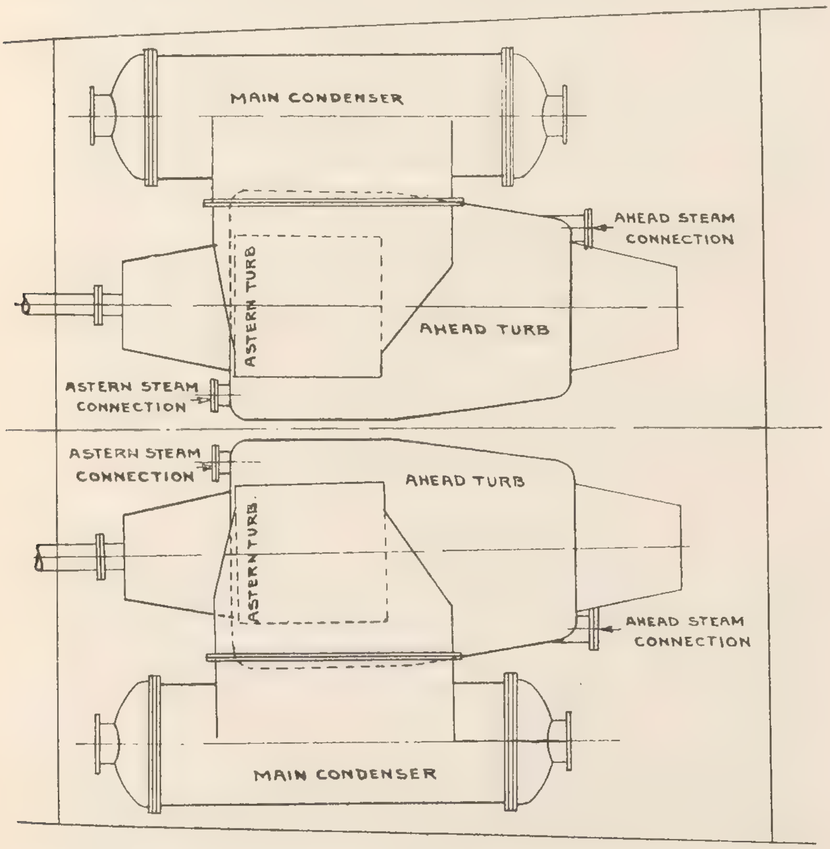

Fig. 1.

The present-day practice for the above classes of propellers direct coupled to turbine machinery will be fairly well represented by multiplying the above figures by 3. This does not represent the early conditions involved with turbine propulsion, where much higher revolutions obtained, but represents the compromise between turbine efficiency and propeller efficiency, in the course of which each has been greatly improved. The total power

developed in the extremes of the three classes of vessels has been more than quadrupled, and the development of combination machinery followed by the modern reduction gear has brought all classes of ships within the economical field of the turbine.

The following chapter gives a general outline of the various methods of application that are now in operation, together with the general class of work for which each seems best adapted.

TURBINES COUPLED DIRECT TO PROPELLER SHAFTING.

Fig. 1 shows a typical two-shaft destroyer arrangement of impulse turbines. Each shaft is driven by an independent ahead and astern turbine, the latter being arranged in the exhaust casing. The blading system is arranged to permit the full drop from maximum admission pressure to final exhaust pressure being completed in each unit. This arrangement combines exceptionally good maneuvering qualities with economical operation within a limited range and will probably continue to be applied extensively to this class of vessel. Each turbine exhausts into its own condenser, with separate air and circulating pumps for each, thus minimizing the chances of total disablement in the event of breakdown.*

Fig. 2 shows the usual two-shaft arrangement for Parsons pure reaction turbines which are arranged in series, and which is specially applicable to destroyers. The port shaft is driven by a high-pressure turbine, in which the steam at initial pressure is expanded down to approximately 23 pounds absolute and which exhausts through the receiver pipe and non-return valve to the low-pressure turbine on the starboard shaft, the final pressure drop being completed in this turbine, which also includes the usual astern blading in its exhaust casing. An independent astern turbine is fitted to the port shaft, with exhaust connection direct to condenser.

The exhaust pipe from high-pressure ahead turbine is also

* "Impulse Marine Turbines in Germany", The Engineer (London), March 18, 1910.

Machinery of the French Destroyers "Fourche" and "Faulx", The Engineer, February 7, 1913.

U. S. Destroyers "Perkins" and "Sterrett", Engineering (London), August 18, 1911.

provided with a valve-controlled connection to the condenser, to permit this turbine being operated independently ahead and astern. A separate live-steam connection provided to the inlet belt of the low-pressure permits operation in the ahead direction independently of the high-pressure turbine, and each astern turbine is also provided with a separate steam connection and valve. With this arrangement slightly better economy in steam consumption can be obtained compared with the two-shaft impulse arrangement, shown in Fig. 1, owing to the fact that the series arrangement is to all intents a single unit, the total volume

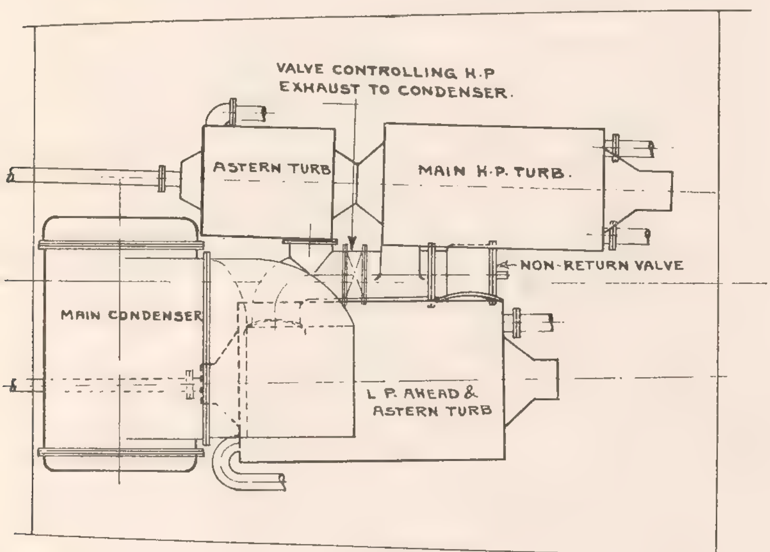

Fig. 2.

of steam passing through one blading system. It follows that a comparison of the two types is equivalent to comparing one large unit of a given power with two small units, both systems developing the same total power. The two-shaft series arrangement lacks the advantage of duplicate units, involves usually a single condenser, and necessitates operating the additional valve in high-pressure turbine exhaust to condenser when changing from full speed ahead to maneuvering conditions, and vice versa. If the blading in the high-pressure and low-pressure turbines is proportioned for an equal division of power between the two shafts

at full power, an unequal division results at reduced speeds, which, however, does not prevent good overall results being obtained, even when operating at one-half maximum power.

Abroad, some two-shaft Parsons installations have been built with independent turbines on each shaft, and in which the high-

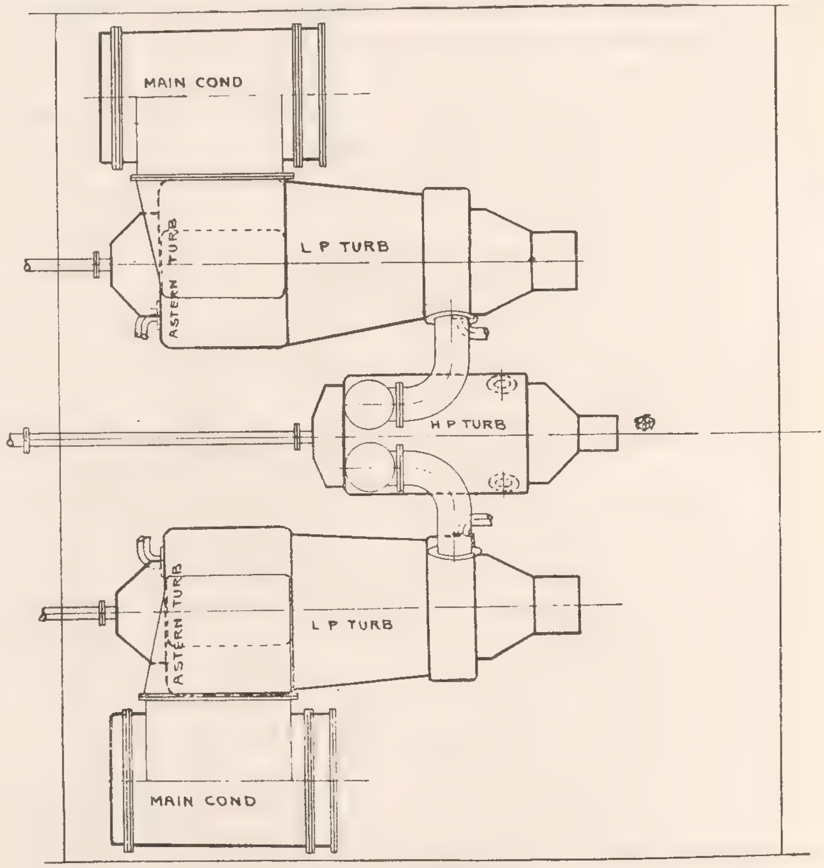

Fig. 3.

pressure reaction part is replaced with a compounded-velocity impulse stage mounted on the forward end of drum.*

Fig. 2 shows arrangement of machinery installed in U. S. Destroyers "Conyngham" and "Porter", to be completed in 1915.

* U. S. Destroyers "Cassin" and "Cummings", Journal American Society Naval Engineers, August, 1913.

Fig. 3 shows the typical arrangement of Parsons turbines in series driving three shafts. The center shaft is driven by a high-pressure turbine, which exhausts through two non-return valves to the low-pressure turbines on the wing shafts. Astern turbines are fitted in the exhaust casings of the low-pressure turbines, which are also provided with live-steam connections to their ahead inlet belts, thus permitting the wing screws being driven ahead or astern independently of the high-pressure turbine, communication to which is automatically closed, under these conditions, by the non-return valves.

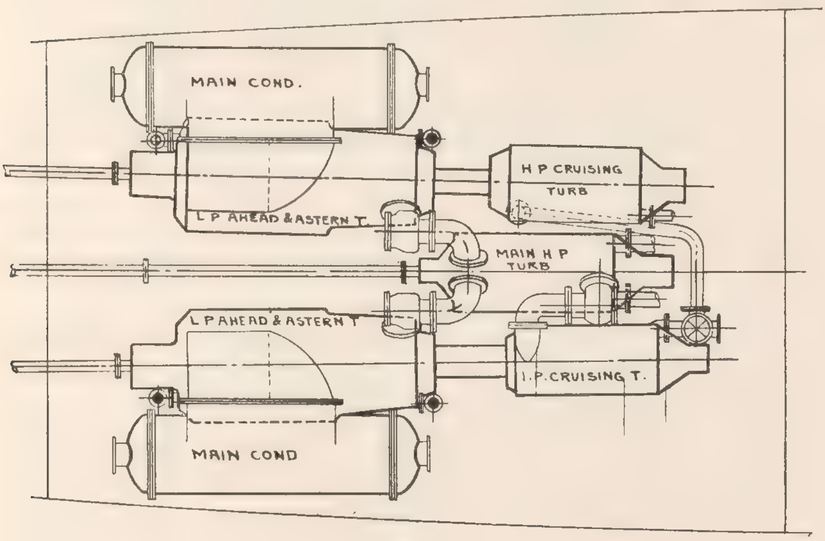

Fig. 4.

This application is suitable for a wide range of work, and, as a result, is represented in the majority of Parsons marine-turbine installations of from 5000 to 30,000 S.H.P. in destroyers, some light cruisers and practically all classes of fast merchant vessels. The use of three propellers permits a higher speed of rotation being maintained, for a given propulsive efficiency, than is possible with two propellers under equal conditions, which results in high overall efficiencies being possible. The fact that the total steam volume passes through one high-pressure system of blading and two low-pressure systems results in the double advantage of avoiding the necessity of excessively short blades in

the early high-pressure stages as well as excessive lengths of blades in the final low-pressure stages. The low-pressure turbines are duplicate units, each with its independent condensing plant, so that not only can either low-pressure turbine be operated independently of the high-pressure or other low-pressure, but the high-pressure turbine can be operated in series with either low-pressure turbine, with the remaining low-pressure turbine cut out by means of gagging down the non-return valve in the pipe leading to the idle turbine.*

Fig. 4 shows the three-shaft arrangement that had been fitted in destroyers and small cruisers, where economical performance at low speeds is of sufficient importance to warrant the two additional cruising turbines. The latter are arranged tandem, with the low-pressure turbines on the wing shafts, to which they are attached by flexible couplings, and both cruising turbines revolve idly in a vacuum when the main high-pressure and two low-pressure turbines are in use under full power. For intermediate cruising speeds, the initial steam is admitted to the intermediate-pressure cruising turbine, which exhausts to the inlet belt of the main high-pressure and from thence to the two low-pressure. Under this condition, the high-pressure cruising turbine is also idle. For low cruising speeds, this turbine receives initial steam and exhausts to the intermediate-pressure cruising turbine, main high-pressure turbine and the two lows in rotation.†

Fig. 5 represents the usual four-shaft Parsons arrangement as fitted on U. S. battleships developing from 30,000 S.H.P. upwards. Each outboard shaft is coupled to a main high-pressure ahead and astern turbine arranged in separate casings, each inboard shaft being connected to the usual form of low-pressure ahead turbines arranged with a low-pressure astern turbine in the exhaust casings. The high-pressure ahead and low-pressure ahead, and high-pressure astern and low-pressure astern, are

* Turbine Machinery, Egyptian Mail Steamers "Heliopolis" and "Cairo", Engineering (London), May 9, 1908.

"Great Northern" Propelling Machinery, International Marine Engineering, December, 1914.

Trials "Great Northern" and "Northern Pacific", Journal American Society Naval Engineers, May, 1915.

† Description and Trial Performance U. S. Destroyer "Beale", Journal American Society Naval Engineers, August, 1912.

connected in series, so the direction of rotation of the two port shafts, as well as of the two starboard shafts, is controlled by their respective ahead and astern throttles. Cruising turbines are shown coupled to the forward ends of the inboard, or low-pressure, turbines so that either one or both can be employed in series with both the main high-pressure and low-pressure ahead turbines.*

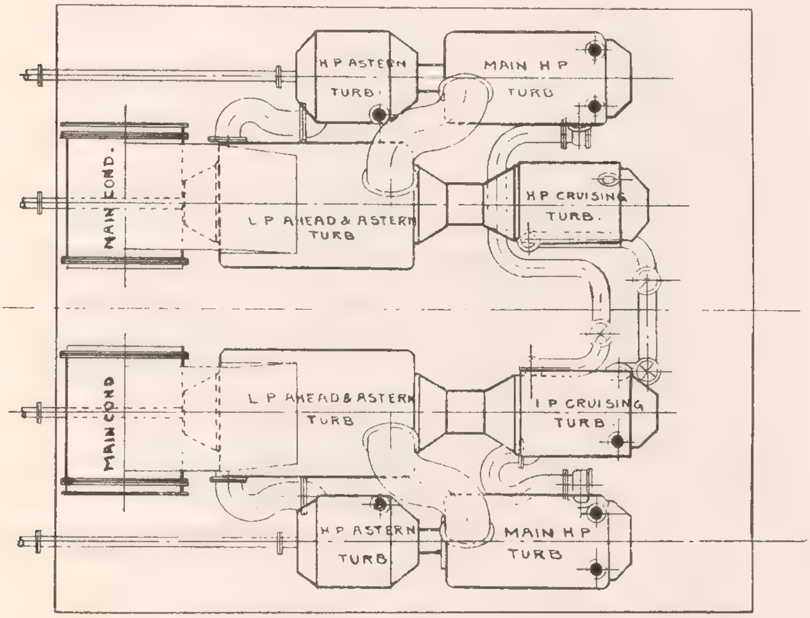

Fig. 5.

The same arrangement of main propelling turbines without the cruising units is also applicable to large merchant vessels.

Fig. 6 shows the four-shaft Parsons turbine arrangement of the "Mauretania" and "Lusitania" of the Cunard Line. The ahead turbines develop about 70,000 S. H. P. under normal conditions, and each shaft therefore transmits about 17,500 S. H. P. The propellers are 16 feet diameter, operating at a speed of 180 revolutions per minute; and in order to obtain the necessary blade speed with the comparatively low speed of rotation, the tur-

* Description and Official Trials U. S. Battleship "Wyoming", Journal American Society of Naval Engineers, August, 1912.

bines are of very large diameter, involving such heavy rotor weights, in the case of the low-pressure turbine, as to necessitate making the low-pressure astern turbine a separate unit, instead of the usual arrangement of combining same with the low-pressure ahead turbine.*

The direct drive arrangement has been generally adopted for all classes of vessels operating at speeds of twenty-one knots

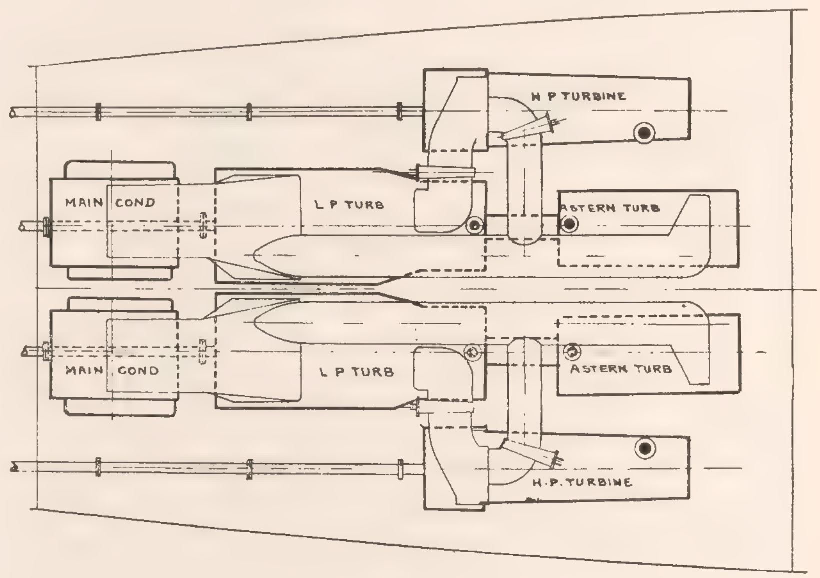

Fig. 6.

and over, and combines the advantages of simplicity, economy and reliability, without excessive total weights of machinery. For vessels with high ratios of power to displacement, it seems likely that this application of the turbine will continue to be the choice of the conservative.

TURBINES AND MECHANICAL REDUCTION GEAR.

Fig. 7 shows the installation of the geared-turbine propelling machinery as applied first in the cargo steamer "Vespasean", by the Parsons Company, in the early part of 1910. There are two

* Machinery of "Mauretania" and "Lusitania", Special Issue of Engineering (London), April 10, 1908.

turbines in series, consisting of a high-pressure ahead and a combined low-pressure ahead and astern, each connected through flexible couplings to pinions located at each side of the large gear on the main line shaft. The ratio of teeth in the large gear to the pinions being 20 to 1 resulted in a turbine speed of 1600 R.P.M., with a propeller speed of 80 R.P.M. This arrangement

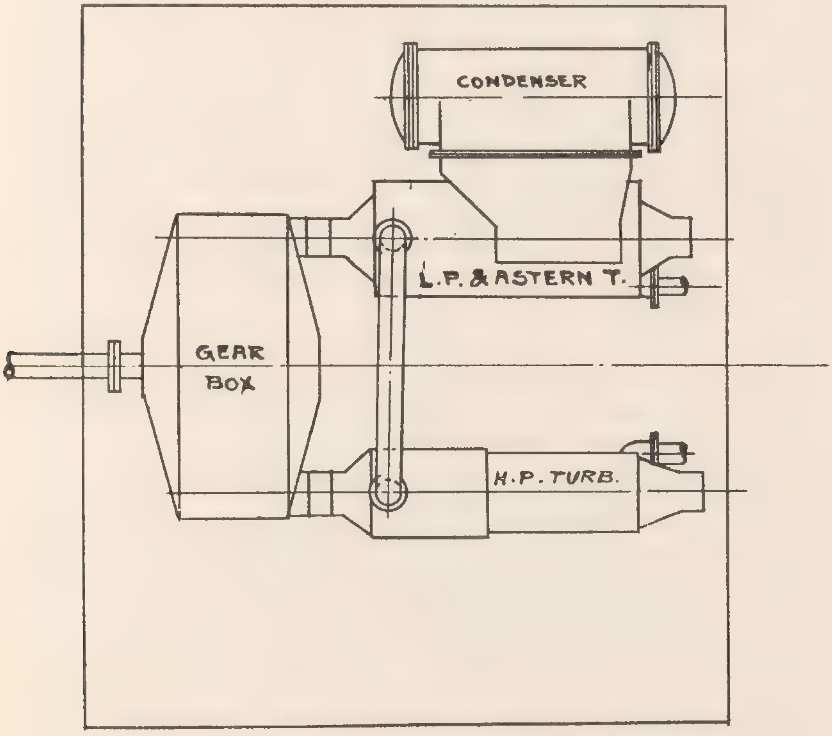

Fig. 7.

enabled the highly economical fast-running turbines to be operated in conjunction with the low propeller speeds necessary for the cargo ship.

The writer had the opportunity of examining the "Vespasean" gears after they had been in operation over two years, and the cutter marks had not entirely disappeared on the wearing surface of the teeth.

As a result of the successful performance of this vessel dur-

ing several years of service, there are a large number of geared-turbine installations already running and under construction.*

Fig. 8 shows one of the late Parsons installations in the Anchor Liner "Tuscania", a twin-screw freight and passenger steamer of 22,000 tons displacement and 17 knots speed. The arrangement of turbines and gearing connecting to each screw is similar to that described for the "Vespasean", except that the gear ratio is 12.5 to 1, owing to the higher speed of vessel, and the turbines are of later design. The machinery is the same as fitted in the Cunard Liner "Transylvania".

Geared turbines have also been installed in destroyers and fast channel steamers and their installation has been seriously considered for battleships. The writer is of the opinion, however, that on fast high-powered Naval vessels, reduction gears will be used principally in connection with the cruising turbines only. The great majority of ocean tonnage is, however, represented by the cargo boat, and for this class of work the geared turbine possesses many advantages and will undoubtedly be used to a greater extent each year as these advantages become better known. In addition to being more economical in fuel, it results in a considerable decrease in machinery weights compared with a quadruple-expansion reciprocating engine, although operating propellers at the same speed. The usual beam-driven air and bilge pumps can be operated by a crank extension of the low-speed shaft. Boiler pressures of from 190 to 200 pounds above atmosphere are suitable, which is an advantage with the large-diameter Scotch boiler usually employed in this class of vessel. The upkeep and cost of attendance are less than with reciprocating machinery; and with the usual arrangement of separate high-pressure and low-pressure turbines, either turbine can be used in an emergency.

* "The Application of the Marine Steam Turbine and Mechanical Gearing to Merchant Ships", Hon. C. A. Parsons, British Institute of Naval Architects, 1910.

"Twelve Months' Experience with Geared Turbines on the Cargo Steamer Vespasean", Hon. C. A. Parsons and R. J. Walker, British Institute of Naval Architects, 1911.

"Geared Turbine Machinery of the Cunard Liner Transylvania", London Engineering, January 29, 1915; also "Description of Geared Turbine Machinery of the Transylvania and Tuscania", Engineering, February 12, 1915.

The disadvantages that have been associated with gearing are noise and liability of pinion teeth breaking. The former has not proven a serious objection, even on passenger ships, and

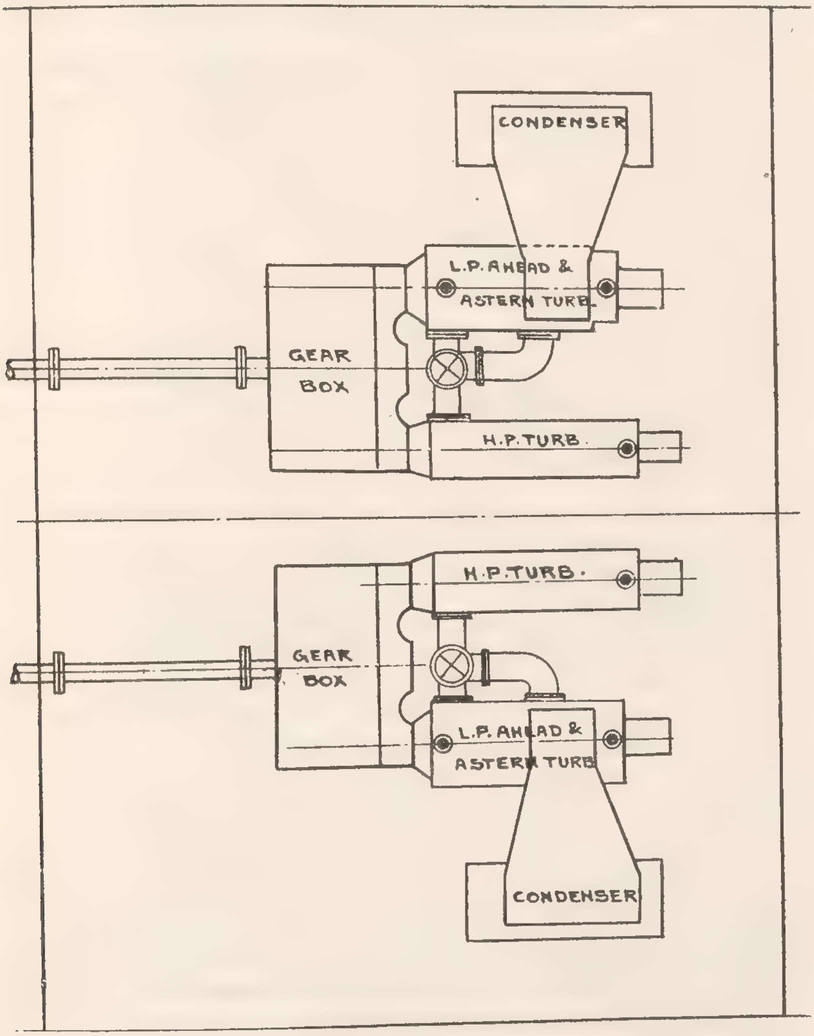

Fig. 8.

could therefore be eliminated as a disadvantage in a freighter. The use of modern alloy-steels, better gear cutting and more liberal gear proportions results in the gears being no more liable to breakage than the reciprocating parts of ordinary engines.

Nearly all breakage has occurred in the pinion due to its greater usage. A spare set of pinions represents a very little outlay and their installation is a small matter.

TURBO-ELECTRIC TRANSMISSIONS.

Fig. 9 shows the system of turbo-electric propulsion as installed in the collier "Jupiter",* which has been developed by

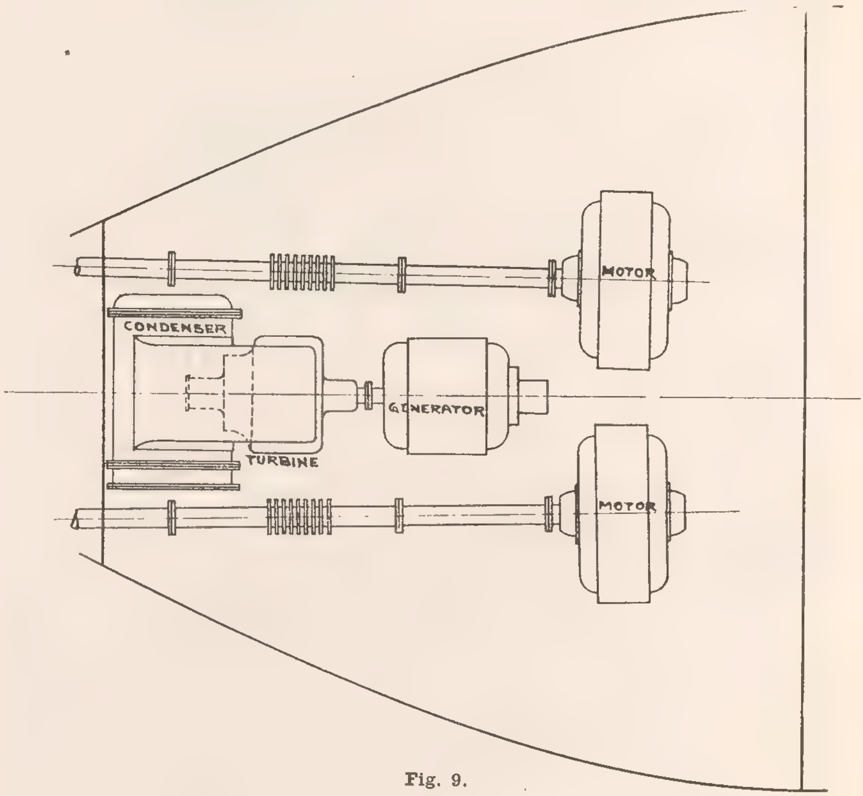

Fig. 9.

W. L. R. Emmet, of the General Electric Company, the machinery being built by this firm. There are two propellers, each being driven by a 36-pole induction motor, the normal revolutions at full power being 110 per minute. The current for both motors

*(See description of Propelling Machinery, U. S. Fleet Collier "Jupiter", Journal of the American Society of Naval Engineers, 1913. Also operation and trials of "Jupiter" in Journal of the American Society of Naval Engineers, 1914.)

is supplied by a single turbine-driven alternator of the power-plant type, running at 2000 R.P.M., the exciting current being supplied by one of the ship's lighting sets. The generator and turbine ordinarily run at a constant speed under control of an automatic governor, the motors driving the propellers being maneuvered by ahead and astern oil switches interlocked with the necessary switches for controlling the fields and levers for short circuiting the starting resistances. Resistances are provided for use on the motor circuit when maneuvering, but for continued running at reduced speeds, arrangements for reducing the generator speed through the governor gear are provided.

This installation has been in service for over a year and its performance has been generally satisfactory, although the results obtained indicate that other forms of propulsion are more suitable for this class of vessels. The advantages claimed for this system would appear to apply more to vessels of the battleship and cruiser class, where economy at reduced speeds is of relatively greater importance. With the four motors and two turbo-generators proposed for this type of ship, a wide range of economical cruising speed is possible, by varying the number of active poles of the motors and by running only one of the generating sets and two propelling motors at speeds requiring less than half of the maximum power.

This system is really an electric reduction gear with a variable economical reduction ratio. The efficiency of transmission includes generator and motor losses, so that not more than 90% of the energy developed by the turbine is available for driving the propellers at maximum power, and at reduced powers this percentage is necessarily reduced. The maneuvering of large motors, including also their source of energy, necessarily involves more functions than are necessary with turbines driving propellers direct or through gearing, and the electrical connections carrying alternating currents of high potential are regarded generally, at the present state of the development, with more or less prejudice.

HYDRAULIC TRANSFORMERS OR TRANSMITTERS.

Fig. 10 is an outline arrangement of the turbines and Föttinger Transmitters in a fast twin-screw channel steamer. As

the functions of reversing and reducing speed of the propeller are performed by the transmitter, the turbines run in one direction at constant speed under control of governors while the vessel is under way. It is considered best not to exceed a 5 to 1 ratio, as the efficiency falls off with increasing ratios. The main tur-

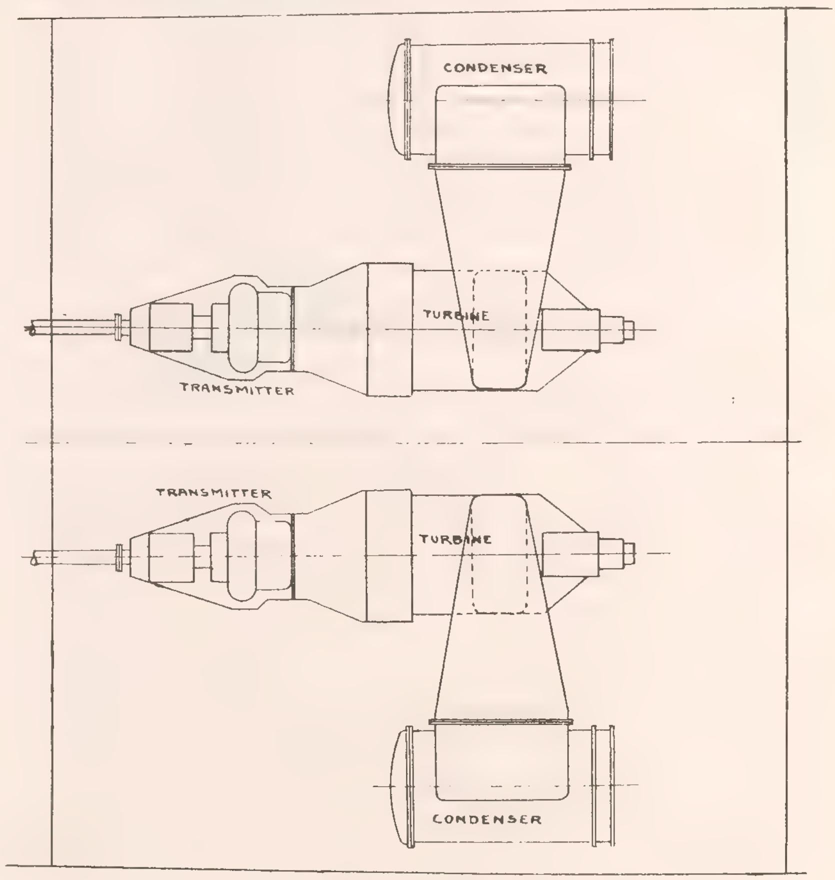

Fig. 10.

bines can be run at fairly high speed, which, with the absence of the astern turbine, permits of a very simple and rugged design. The transmitter and its attachments, however, more than offset the simplicity of the turbines, and consist of two circular chambers enclosing extensions of the turbine spindle and propeller shafting, the after chamber containing the ahead transmitter and

the forward chamber the astern transmitter. Either is brought into action by filling the chamber with water, the other being previously emptied. Each chamber contains two moving elements—(1) an impeller of the centrifugal-pump type secured to the turbine-spindle extension, and (2) a runner of the hydraulic-turbine type secured to the propeller-shaft extension. The buckets of the ahead and astern runner are, of course, arranged for opposite directions of rotation. Owing to the relatively low speed, the ahead runner is made in two stages, with guide vanes between the first and second stages. In other words, water is delivered from the high-speed single-stage impeller driven by the turbine to a slow-speed two-stage runner connected to the shafting driving the propeller. The water discharged from the second stage passes directly into the suction, or inlet, of the turbine-driven impeller. The astern transmitter has a single-stage runner, as high efficiency is not required, and guide blades are fitted to direct the discharge water from the impeller into the astern runner, the direction of rotation of these two elements being opposite. A special pump is required to supply the water for alternately filling the transmitters when maneuvering and to make up leakage when under way. Arrangements are also provided for supplying to and withdrawing from the transmitter system a portion of the boiler feed-water, in order to prevent the water in transmitter system reaching the boiling point. Thus a part of the losses of the transmitter is utilized in raising the temperature of feed water going to boilers. This system of transmission permits of fairly high turbine speeds being obtained in connection with moderate propeller speeds, without the noise that exists to some extent with gearing. The omission of the astern turbines shortens the driving unit between bearings and avoids the stresses in blading involved by reversing the direction of turbine rotation. On the other hand, the construction of the transformers necessitates excessive overhang of the rotating members, with a considerable number of labyrinth packings. The principle is ingenious, but features of design are involved that have always been looked upon with disfavor. They require workmanship of the very highest order and repairs or replacements could not be undertaken by the average repair yard. The reduction ratio attainable is not considered sufficient to permit of the system

being applied to slow vessels with economy. The efficiency of the transformers under best conditions is claimed to be 88%, or at least 10% less than that of modern mechanical reduction gearing. It is better adapted to higher-speed and higher-powered vessels, and cannot hope to compete with the all-gear drive for the cargo type of vessel. Its one chief advantage is in maneuvering qualities.*

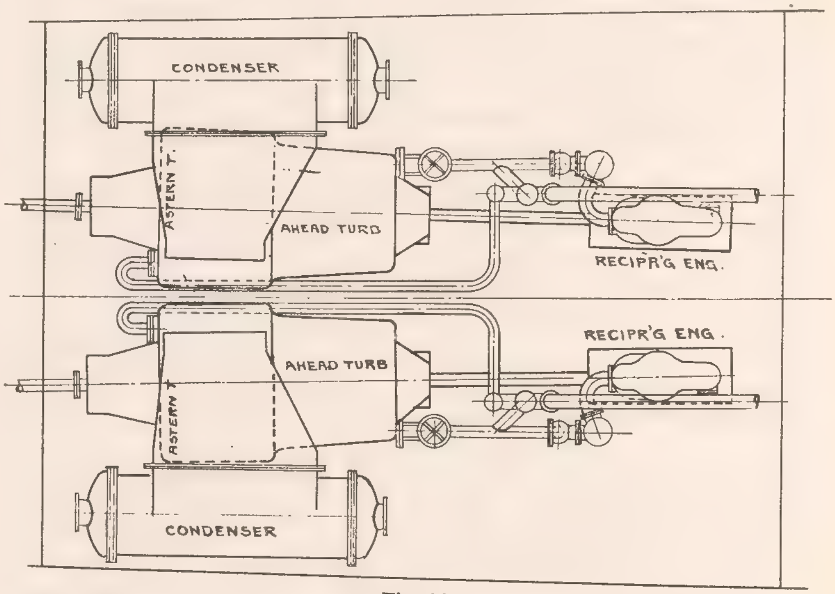

Fig. 11.

RECIPROCATING ENGINES AND TURBINES IN COMBINATION.

The first installation of this kind was made by the Parsons Company in the British Destroyer ''Velox'', built in 1902, with the object of improving the economy at cruising speeds. The two engines on the ''Velox'' were coupled to the forward ends of the low-pressure, or wing shafts, the exhaust from both passing through the main high-pressure turbine and the two low-pressure turbines to the condensers.

Fig. 11 shows an arrangement of this character applied to recent destroyers built for the U. S. Navy, the engines being in

*''Description of Föttinger Transmitters and Turbines of the Hamburg-American S. S. 'Königin Luise' '', London Engineering, Dec. 12, 1913.

combination with impulse turbines on two shafts. In this case, the reciprocating engines are employed in conjunction with the turbines at cruising speeds only.*

Through the development of the "Velox" arrangement, Sir Charles Parsons saw that the essential features could be applied to merchant vessels of intermediate power and speed to advantage, and an installation embodying the results of previous experi-

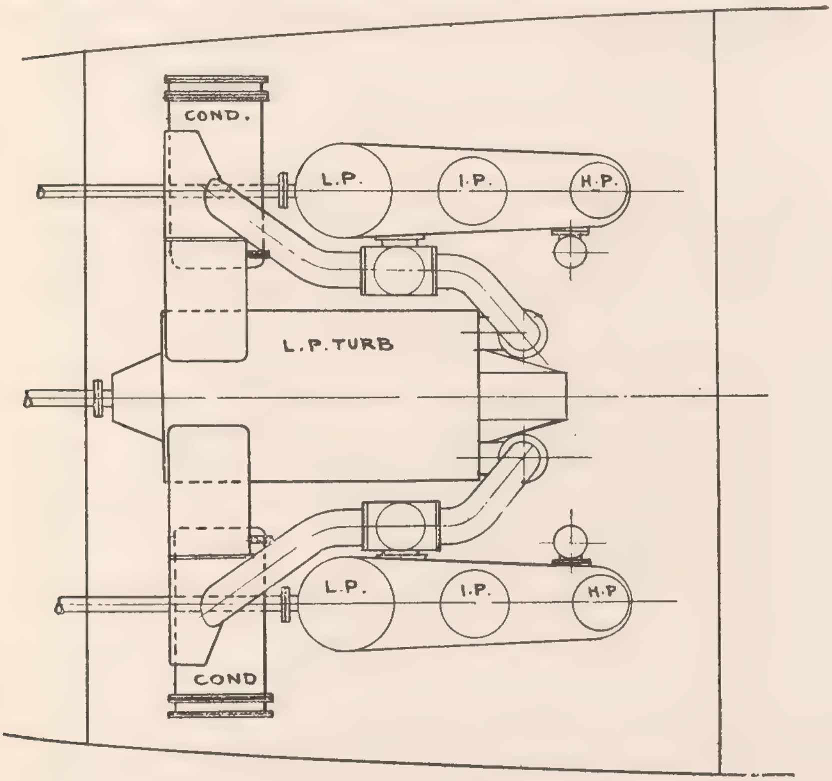

Fig. 12.

ence was made in the New Zealand Shipping Company's steamer "Otake", delivered in 1908.†

Fig. 12 shows the machinery layout for this vessel, from which it will be noted there are three propellers, those on the

* Description and Trials U. S. Destroyer "Nicholson", Journal American Society Naval Engineers, May, 1915.

† Notes on Trials and Performances of the S. S. "Otake", Transaction of the Institute of Engineers and Shipbuilders in Scotland, August, 1909.

wing shafts being driven by triple-expansion engines, both of which exhaust into the turbine on the center shaft, which in turn exhausts into the main condensers. The reciprocating engines are fitted with the ordinary reversing gear, which also operates a change valve in the exhaust passage from each engine to the turbine, so arranged as to direct the exhaust from the engine direct to the condenser, through a separate exhaust pipe, when they are in astern gear. Provision is also made in the operating gear of the change valve to permit of the engines being man-

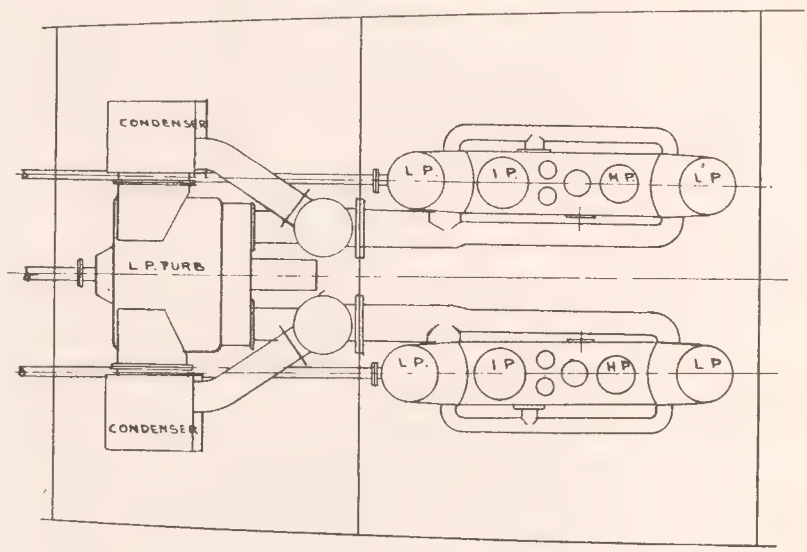

Fig. 13.

euvered both ahead and astern independently of the turbine which is arranged for ahead working only.

Fig. 13 gives the arrangement of combination machinery in the White Star Company's S. S. "Olympic", which is similar to the "Otake" installation.* This is the largest installation of this type that is in operation, being upwards of 46,000 combined I.H.P. and S.H.P.

This arrangement is generally considered to effect about 15% saving on coal over the ordinary reciprocating machinery. The usual exhaust pressure to turbine is about 10 lbs. absolute.

* "Olympic" Souvenir Number of The Shipbuilder, June, 1911.

Under 5 lbs. absolute there is no appreciable advantage over the all reciprocating.

Fig. 14 shows a four-shaft installation of this type, in the S. S. "Lutetia", of 19,000 H. P.* The four-shaft is supposed to give a better over-all efficiency than the three-shaft, due to being able to use a higher exhaust pressure to turbines. The propulsive efficiency is also possibly better, with some saving in weight.

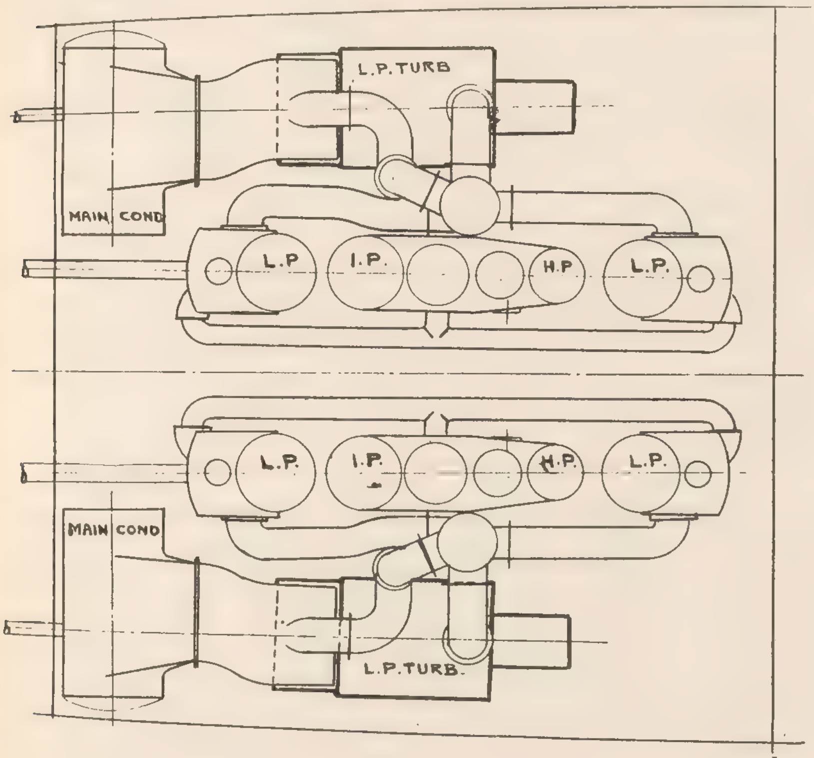

Fig. 14.

The advantage, however, in maneuvering qualities is with the three-shaft, for which reason the three-shaft is more used.

The combination of reciprocating engines and turbines results in several important advantages, as the engine and turbine economy is very high with comparatively low propeller speeds, resulting in high over-all efficiencies. The engine-driven pro-

* Machinery described: The Engineer (London), May 9, 1913; Engineering (London), October 16, 1914.

pellers are of course driven at the speeds of ordinary engine practice, and the low pressure and large specific volume of steam for which the turbine is designed permits large diameters and, consequently, low revolutions. The usual labyrinth dummies can also be omitted, making the forward drum-spider closed between the arms, the resulting unbalanced steam thrust being opposed by the propeller thrust. The reciprocating engines are arranged to exhaust direct to condenser when maneuvering, and thus provide most of the advantages of the ordinary twin-screw arrangement when docking.

The disadvantages involved are that the weight of machinery and space occupied are greater than required for other installations; and in vessels of lower speeds for freight and passenger service, the three shaft tunnels practically take up all the after hold space below the lower deck. This is a point in favor of the all-gear arrangement for this class of vessels.

The combination machinery is adapted for large ships of from 17- to 21-knots speed designed for long voyages where the gain in fuel consumption more than compensates for the weight and space involved.

COMPARATIVE PERFORMANCE OF DIFFERENT SYSTEMS.

The following table gives the average performance, under favorable conditions and applications, of the systems described in the preceding pages, also the losses involved between the energy delivered by the turbine and the effective work delivered by the propeller as axial thrust. The most important of these are the transmission and propeller losses, which are the factors to be considered in determining the scope of the various systems, so far as economy is concerned. Weight and space occupied have varying values in different classes of ships, but may prove the deciding factors in certain classes of work. It will be noted that lower shafting losses are given for the direct-drive arrangement, due to better lubrication and absence of thrust losses, the latter being covered by the water rates per B.H.P. of the turbine. In the remaining systems, some form of thrust bearing has to be introduced to take the propeller thrust, except in the turbine-driven shaft of the combination system. The engine losses given for the combination system are based on the assumption that

Losses given in percent of total power developed.	Turbines connected direct to propeller shafting.	Turbine drive through mechanical reduction gear.	Turbine and electric transmission.	Turbines and hydraulic transmitter Föttinger type.	Combination machinery—2 reciprocating engines and 1 L.P. turbine.
Turbine water rates Lbs. per S.H.P.-hour	11½ to 12	10½ to 11	10½ to 11	10½ to 11	Combined I.H.P. and S.H.P. 10½ to 11
Mechanical reduction-gear losses	....	2%	....	....	....
Generator and motor losses	....	....	10%	....	....
Hydraulic transformer losses	....	....	....	14%	....
Reciprocating engine losses in combination	....	....	....	....	5.3%
Losses in thrust, line and propeller shafting	1½%	2½%	2½%	2½%	2½%
Propulsive efficiencies	53%	65%	65%	60%	60%
Water rate per E.H.P.	22 to 23	17 to 17.7	18.4 to 19.3	20.8 to 21.9	19 to 19.9

the actual B. H. P. delivered is 0.92 of the I.H.P. of the engines; and for a three-shaft installation with the power equally divided between each unit, the engine losses would be 5.3%

It seems probable that the steady development of mechanical reduction gears for the higher powers will correspondingly limit the future application of the combination system.

There have been two installations of Föttinger transmissions made in merchant vessels, but one of these was destroyed after a short period of service at the beginning of the present European War, the other having been finished but not put in service. The extent to which this system will be applied in the future is problematical; and until a representative installation has stood the test of several years' service, its application will not be very extensive.

The electric transmission system may prove of value in large naval vessels where economy at reduced speeds is of paramount importance but it does not seem to have any advantages that will warrant its application in merchant work.

The combination of geared cruising units with direct drive turbines for full power, seems to be the tendency for modern battleship installations, and the direct connected turbine will probably continue to apply to very fast high-powered ships.

The installations of Parsons turbines alone for all classes of vessels in 1914 amounted to about ten millions shaft horsepower. Reliable figures for installations of impulse turbines of various forms are not available, but the total probably reaches well over one million shaft horsepower.

DISCUSSION

Mr. Davis. **Mr. W. J. Davis, Jr.,*** said that the author of this paper, as well as Lieut. Commander H. C. Dinger, author of "The Development of the Marine Steam Turbine", had overlooked one point. The electric drive, he said, has excellent maneuvering qualities. The control of the ship is made very simple and positive by the use of switches instead of throttles, valves, gearing, etc. The electric drive requires but two turbines, only one of which is operating ordinarily. Other types of drive, he said, are much more complex, requiring steam piping and connections for 12 turbines, as follows: 4 direct-connected turbines for steady cruising conditions, 4 reversing turbines, 4 general turbines for maneuvering.

*Pacific Coast Engineer, General Electric Co., San Francisco, Calif.

Mr. J. F. Metten, in closing, said that from Mr. Davis' remarks it might be inferred that the control of an electric-driven ship is simpler than the steam-driven ship. It is only necessary to read the description of the switch manipulations necessary in handling the "Jupiter", contained in the May Journal of the American Society of Naval Engineers, to convince anyone that the electric drive is inferior to the ordinary throttle-controlled turbine drive in this respect. Mr. Metten.

Mr. Metten says that he is not familiar with any battleship installation of propelling machinery that comprises four direct-connected turbines for steady cruising conditions, four reversing turbines, four general turbines for maneuvering. It would also have been more to the point had Mr. Davis stated that the electric drive requires two main turbines, two alternating generators connected to same; two small turbines, two direct-current exciters connected to same; and four large motors connected to propeller shafts; together with the steam and exhaust piping to the main and exciter turbines, and the electrical connections from the two exciters, two generators and four propelling motors.

Paper No. 213

RECENT DEVELOPMENTS IN MARINE ENGINEERING IN JAPAN.

By

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Tokyo, Japan

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1. In describing the developments in marine engineering in Japan, particular reference must be made to the Ship-building Encouragement Acts, first promulgated in 1896, soon after the Japan-China War, as it is mainly the outcome of those Acts that the ship-building and marine engineering industry has made such rapid strides; nearly all marine engines of considerable size were built under the protection of the said Acts, excepting of course those for naval purposes.

2. As to the building of steam engines for the merchant marine of Japan at an early date, very little is known except that small engines, either of simple or compound type and not exceeding 300 hp., were made at navy yards or by foreign firms in the open ports for coasting steamers. The engines of "Kosuge Maru" built in 1883 by the government works at Nagasaki (the predecessors of the Mitsubishi Dockyard and Engine Works of the present day) were the largest compound engines ever made in Japan, and have the following dimensions:

Dia. of H.P. cylinder	36 ins. (0.914 m.)
Dia. of L.P. cylinder	63 ins. (1.60 m.)
Stroke	36 ins. (0.914 m.)
Steam pressure	60 lbs. per sq. in. (4.08 atmos.)
I.H.P.	642

Triple-expansion engines were imported in 1888 from Great Britain, and in 1890 the Mitsubishi Dockyard built the first home-made triple-expansion engines, for the coasting steamer

"Chikugogawa Maru", the principal dimensions being as follows:

Dia. of cylinders	15 ins., 23 ins., 39 ins. (0.381 m.) (0.584 m.) (0.991 m.)
Length of stroke	30 ins. (0.762 m.)
Steam pressure	155 lbs. per sq. in. (10.546 Atmos.)
I.H.P.	472

The Kawasaki Dockyard Co. and the Osaka Iron Works soon followed the example and there were more than a dozen of such engines at the end of 1897 made by these three firms, the most conspicuous among them being the engines of "Suma Maru", constructed by the Mitsubishi and having the following dimensions:

Dia. of cylinders	18½ ins., 30 ins., 49½ ins. (0.470 m.) (0.762 m.) (1.257 m.)
Length of stroke	36 ins. (0.914 m.)
Steam pressure	150 lbs. per sq. in. (10.206 Atmos.)
I.H.P.	795

These, with the engines of "Miyajima Maru", of about same size and made by the same firm, were the largest built before promulgation of the Ship-building Encouragement Acts of 1896.

3. As stated in the preceding paragraph, the marine engine construction of Japan was still in a rudimentary state at the time of the Japan-China War, and the necessity of protection and encouragement for ship-building and marine engineering was keenly felt by the nation. The Encouragement Acts were promulgated in March, 1896, to be in force from October 1st of the same year. According to the Acts, a subsidy of twelve yen (six dollars) and twenty yen (ten dollars) per ton was given for iron or steel vessels above 700 tons and 1000 tons respectively, and five yen per i.h.p. for the machinery. The bounty was considered sufficient to cover the freight, duty and other expenses of the imported materials, to bring down the price of home-made steamers to something near that of the imported ones, thus pro-

moting the ship-building and engineering industry at home. The Encouragement Acts of 1896 were to be in force for fifteen years, but in 1909 they were revised; the new Acts then passed by the Diet were to be in force from 1910 for a period of ten years. According to these new Acts, steel vessels of above 1000 tons only were granted a subsidy of from eleven yen to twenty-two yen per ton gross according to their class, while the subsidy for the machinery remained unchanged.

4. The number of vessels with new engines constructed under the Acts at the end of May 1915 totaled 126, nearly 30 per cent of them being under 1000 h.p., while there were 7 vessels fitted with engines of more than 10,000 h.p.

The aggregate horsepower was 400,476, making average power of each ship 3178. (See Table I.) For the above-mentioned engines, the subsidy granted amounts to 2,002,380 yen, averaging 111,243 yen per year.

There are 52 vessels under construction at present, with total horsepower of 166,300, to be completed not later than the end of next year. (See Table II.)

5. According to the Encouragement Acts, the engine-builders must satisfy a certain qualification as to the equipments of the works and the capability of their engineers. There are regulations for the construction of machinery and testing of materials, based mostly on Lloyd's Rules, but more strict in certain items. Permission for the adoption of foreign-made materials and equipments is restricted to special materials and patented articles.

These restrictions have limited the builders of large engines to a few firms which build the hull as well, the Mitsubishi Dockyard and Engine Works of Nagasaki and Kobe, and the Kawasaki Dockyard Co. of Kobe being the two principal builders. The output of the engines for various firms during the years 1897-1904 is as follows. (See also Table III.)

	I.H.P.
Mitsubishi Dockyard and Engine Works	232,482
Kawasaki Dockyard Co.	132,375
Osaka Iron Works	31,923
Ishikawajima Shipyard, Tokyo	2,004
Ono Iron Works and Shipyard, Osaka	531
Uraga Dock Co.	1,161

Most of the above firms have also constructed engines for Naval use, some of them developing as much as 64,000 horsepower per set.

6. Turning now to the types of engines, cargo vessels and intermediate vessels have mostly had reciprocating engines of triple-expansion type, twin-screws being most prevalent in the latter class of vessels. In passenger vessels, steam turbines have lately been adopted, while geared turbines and the combination system are quickly coming into use for the intermediate boats. The following is the classification of engines according to their type. (See also Table IV.)

		No. of vessels to which such is fitted	I.H.P.
Reciprocating Engines	Single screw	73	98,350
	Twin screws	46	223,587
Steam Turbines (geared turbines included)	Twin screws	3	26,841
	Triple screws	3	39,917
Combination System	Triple screws	1	11,781

7. Perhaps it will be worth while to go into more detailed description of some of the principal engines hitherto made in the home yards.

The first large engines built under the subvention were those of "Hitachi Maru", completed in 1898 at the Mitsubishi Dockyard and Engine Works. These were triple-expansion twin-screw engines having the following dimensions:

Dia. of cylinders	H.P. 20 ins., (0.508 m.) I.P. 33½ ins., (0.851 m.) L.P. 56 ins. (1.422 m.)
Length of stroke	48 ins. (1.219 m.)
Boilers	2 single-ended and 2 double-ended cylindrical, 13 ft. 3 ins. dia. (4.04 m.)
Working pressure	200 lbs. per sq. in. (13.61 atmos.)
I.H.P.	3890

The engines, however, were constructed under the same design as those of sister ships built in Great Britain; the home builders got the assistance of European engineers and imported

most of the steel materials and auxiliary machinery from abroad. This was considered to be a prudent course in undertaking the construction of engines of such a size as they had never experienced before.

8. The engines built by the Mitsubishi Works grew in size and number year after year, and soon the works were able to dispense with European aid, except a part of the steel materials and patented articles. In 1902, they built the quadruple-expansion engines for two ore-carriers, with the following dimensions:

Dia. of cylinders......	H.P. 20 ins. (0.508 m.), 1st I.P. 29 ins. (0.737 m.), 2nd I.P. 42 ins. (1.067 m.), L.P. 60 ins. (1.524 m.)
Length of stroke......	45 ins. (1.143 m.)
Boiler	1 double-ended cylindrical, 15 ft. 6 ins. dia. by 17 ft. 5½ ins. long (4.72 x 5.32 m.)
Working pressure....	200 lbs. per sq. in. (13.61 atmos.)

On the full-speed trial these developed 2280 and 2366 i.h.p. with the consumption of 1.516 and 1.525 lbs. (0.686-0.691 kg.) of Japanese coal per i.h.p. per hour respectively. This type of engine, however, was not welcomed by shipowners, as the saving in fuel was not enough to balance the interest of increased cost, owing to cheapness of coal in Japan.

9. The triple expansion engines of ''Nikko Maru'', one of the Nippon Yusen Kaisha's Australian liners, are the largest reciprocating engines, developing 6700 horsepower in a single set. They are also the highest speed engines, the piston speed being 890 ft. (271.27 m.) per min. at trial.

The following are the principal dimensions:

Dia. of cylinders......	H.P. 31 ins. (0.787 m.), I.P. 51 ins. (1.295 m.), L.P. 85 ins. (2.159 m.)
Length of stroke......	54 ins. (1.372 m.)
No. of boilers............	2 single-ended and 2 double-ended cylindrical, 15 ft. 6 ins. dia. (4.72 m.)
Working pressure....	185 lbs. per sq. in. (12.60 atmos.)
I.H.P.	6780
Speed of ship............	17.77 knots.

The shaft for these engines was imported from Great Britain, as the works could not make forgings of such size. The ''lock-

fast" iron and continuous brass sleeve for propeller shaft were first introduced for this vessel.

10. The Kawasaki Dockyard constructed many sets of engines for shallow-draught steamers navigating the Yangtsze River, the largest among them being triple-expansion twin-screw engines for three similar vessels, each developing 3360 horsepower with a piston speed of 830 ft. (252.98 m.) per min.

11. The latest and largest sets of reciprocating engines are those for Nippon Yusen Kaisha's 12,000-ton European liners, two of which were built by the Mitsubishi and one by the Kawasaki. Their engines are of triple-expansion twin-screw type, having the diameters of cylinders 28 ins. (0.711 m.), 47 ins. (1.194 m.), 79 ins. (2.007 m.) and length of stroke 51 ins. (1.295 m.), steam being supplied by 7 single-ended boilers, 15 ft. 6 ins. (4.72 m.) diameter and 11 ft. 9 ins. (3.58 m.) long, with working pressure of 200 lbs. per sq. in. (13.61 atmos.). They developed 11,500 i.h.p., with coal consumption of 1.294 lbs. (0.586 kg.) of Japanese coal per i.h.p. per hour.

12. As the subsidy for engine construction is given for the power they actually develop on trial trip, as stated above, the natural tendency for the makers was to design and construct them so as to develop the highest possible power on that occasion with comparatively small engines.

The usual way resorted to was later cut-off of valves and forcing of boilers. There is one instance where a reduction of about 20 per cent in coal consumption was attained afterwards, mainly from alteration of valve settings in one of these engines. These practices, however, were put to an end by stricter precaution of owners and the intelligent policy of builders wishing to get a reputation in the long run rather than immediate returns. Thus, the engines for the above vessels achieved a remarkable success on their voyage to Europe, consuming about 1.28 lbs. (0.580 kg.) of Durham coal per i.h.p. per hour. The weight of engines was also cut down considerably, compared with their prototype. The accompanying figures afford some idea of such reduction.

	Kashima Maru		Yasaka Maru		Difference	
	§Tons	Lbs.	Tons	Lbs.	Tons	Lbs.
Weight of engine beds (2 sets), bearings, shafts, etc., included	46	1419	41	1118	5	321
Ditto per I.H.P.		10.418		8.083		2.325
Weight of cylinders, complete (2 sets)	97	100	81	812	15	1528
Ditto per I.H.P.		21.68		15.848		5.832
Date built	1913		1914			

13. Parsons' steam turbines were first introduced in 1907, fitted on two channel steamers built by Wm. Denny and Bros. of Dumbarton. These had small three-shaft turbines of about 4000 horsepower. In the following year the Mitsubishi Dockyard imported two sets of turbines of the same type, but larger in size, to be fitted on "Tenyo Maru" and "Chiyo Maru" built at their own yard at Nagasaki. These boats made 20½ knots on their trial trips with 19,000 shaft horsepower. The Mitsubishi got the sole license for the manufacture of Parsons' turbines and the first engines they built were those of "Sakura Maru", one of the Volunteer Fleet steamers, in 1908. The following are the principal dimensions:

Dia. and length of H.P. Rotor	4 ft. by 6 ft. 5 ins. (1.219 m. by 1.955 m.)
Dia. and length of L.P. Rotors	5 ft. 8 ins. by 7 ft. 8 ins. (1.73 m. by 2.34 m.)
Boilers	6 Miyabara double-ended water-tube boilers
Steam pressure	200 lbs. (13.61 atmos.) at boilers and 160 lbs. (10.90 atmos.) at engines
S.H.P.	8535
Total weight	562 tons

In 1910, the same firm built the turbines of "Shinyo Maru", of the same size as those of the other two Pacific liners mentioned above, but in this case developing 20,050 shaft horsepower, with less weight and lower cost than the others.

14. The Curtis turbines of "Sakaki Maru", the third of the Volunteer Fleet steamers, are the only engines of the kind

§ 1 ton (2000 lbs.) = 0.907 metric ton.

for merchant vessels at present. These were built in 1913 at the Kawasaki Dockyard, the sole licensee for their manufacture in the East; they consist of six wheel stages and a drum carrying one three-bucket stage and a number of one-row bucket stages. The principal dimensions are:

Dia. at pitch circle......	8 ft. (2.438 m.)
Length between centres of bearings........	20 ft. 6 ins. (6.248 m.)
Boilers	8 single-ended cylindrical
Steam pressure...............	215 lbs. (14.64 atmos.) at boilers and 200 lbs. (13.61 atmos.) at engines.
S.H.P.	12,248
Total weight..................	1050 tons.

15. In May of the same year, the Mitsubishi Co. completed the first geared turbines of Parsons type for "Anyo Maru", one of the steamers engaged in the Toyo Kisen Kaisha's South American service, the materials for gearing being imported in the form of forged pieces. She made 15.31 knots at the trial trip with 7470 shaft horsepower, the revolutions of both propellers being 99 per minute. It may not be out of place to mention that Dr. Suyehiro's torsion meter with visible scale was used on her trial and proved to be quite satisfactory, even for such a slow-running engine as this. In "Anyo Maru's" maiden voyage some teeth of one of the pinions were broken, and after a thorough search as to the cause, by many experienced engineers, it was attributed to defective forging; at the same time some modifications in the form of the teeth were suggested and they have been adopted in gears since made. About this time, 1913, the Nippon Yusen Kaisha were contemplating the best type of engines for their new programme of 7500-ton cargo steamers, and they decided to adopt the geared turbines for two of them, while the other two pairs were fitted respectively with reciprocating engines of superheated-steam type and engines of ordinary type. Most of these vessels have been completed lately; comparative results are given in Table VI. There is a repeat order for two geared turbine sets of about the same size, but fitted with an impulse stage, and there is every prospect at present of still wider adoption.

16. One of the Nippon Yusen Kaisha's European liners was fitted in 1913 by the Mitsubishi Works with the combination system of reciprocating engines and Parsons' low-pressure turbine, of the following dimensions:

Reciprocating engines..	2 sets of 27 ins. (0.686 m.) by 42 ins. (1.067 m.) by 66 ins. (1.676 m.) by 48 ins. (1.219 m.) stroke triple-expansion engines
L.P. turbine, dia. and length of rotor..........	11 ft. 1 in. (3.375 m.) by 10 ft. (3.048 m.)
Boilers	6 single-ended cylindrical
I.H.P. of reciprocating engines	7128
S.H.P. of turbine..........	4213
Working pressure..........	200 lbs. per sq. in. (13.61 atmos.)

The anticipated fuel economy was obtained, the figures for full power trial and on service being 1.385 lbs. (0.617 kg.) and 1.221 lbs. (0.554 kg.) respectively, but the complication of the engine room and somewhat more space occupied by the turbines seem to be hindrances to their general adoption.

17. The first steel boiler made in Japan was that of the steam tug "Yugawo Maru". It was made by the Mitsubishi Works in 1887, and had a working pressure of 80 lbs. per sq. in. (5.49 atmos.), the usual practice being 60 lbs. (4.08 atmos.) at that time. Boiler pressure did not increase much above 100 lbs. (6.81 atmos.) until in 1885 the above-named firm made the boiler of the "Chikugogawa Maru", already mentioned as having the first triple-expansion engines; the pressure in the boilers for this vessel was made 150 lbs. (10.206 atmos.). After the promulgation of the Encouragement Act, boilers for 200 lbs. (13.61 atmos.) pressure began to be built, those for "Hitachi Maru" being the first. The pressure for boilers remains at 200 lbs., except in the case of the turbine steamer "Sakaki Maru", where a pressure of 215 lbs. (14.64 atmos.) was adopted. The construction of boilers has made steady progress, so that now those of any size giving the most satisfactory results are possible. As an instance of this, the case of "Tenyo Maru" may be cited; for this ship the Mitsubishi Co. made 13 boilers in a very limited time. The only disadvantage in Japanese engine works at present is that they can not get large boiler plates made at home, the government

steel works at Yawata being still unable to produce plates wider than 8 ft. (2.438 m.)

18. Forced draught of Howden's patent was introduced in 1901 for the boilers of the shallow-draught steamer "Tachang Maru" as a means of reducing the weight of machinery. Since then, in most of the boilers made under the subvention, makers have adopted this system, which has proved in every way a success, besides giving the advantage of greater horsepower generated.

19. Water-tube boilers have not yet been much used except in the navy; the Miyabara boilers for the Volunteer Fleet steamers and the Babcock and Wilcox boilers for two sea-going dredgers being the only examples.

20. The superheating of the steam is of quite recent development, the only ship of any size fitted with the Schmidt system being a 5600-ton passenger steamer completed at the end of last year. The Kawasaki Dockyard Co., which built and engined her, possess the sole license for its manufacture, and are fitting it to six new steamers now under construction. The Mitsubishi Co., on the other hand, made exhaustive trials on a steam trawler of 520 i.h.p. with the superheater patented by Dr. Esaky, the chief designer of the company. The feature of the patent is the twisted superheater tubes to give a retarding effect to the flame. As the result of the trials, they guarantee 10% reduction of fuel with common Japanese coal. They are now fitting these to two 6000-hp. geared-turbine steamers and four others on the stocks.

21. Oil fuel was first adopted in the "Tenyo Maru" and her sister boat. They were afterwards converted to burn coal in half the number of boilers, owing to the uncertainty of supply of fuel oil on this side.

The oil production of Japan, however, has advanced lately, and there is a prospect of its coming into more general use as a fuel.

22. One must not overlook the effect of the Encouragement Law for the building and improving of fishing boats, passed in 1898, upon the development of smaller engines, specially those of oil motors. In 1905 there was only one fishing boat fitted with an oil motor, but now there are more than 2000 vessels, with an aggregate horsepower of 30,000, scattered all over the country.

The following table shows the number and horsepower of motor fishing boats and their annual increase, from 1905 to 1914.

	1905	1906	1907	1908	1909
No. of vessels	1	7	21	82	198
Total B.H.P.	18	107	371	2,159	4,495
Increase in No.	....	6	14	61	116
Increase in B.H.P.	....	79	264	1,788	2,336

	1910	1911	1913	1914
No. of vessels	541	828	1,674	2,073
Total B.H.P.	10,740	14,867	24,300	30,791
Increase in No.	343	287	846	399
Increase in B.H.P.	6,245	4,127	9,433	6,491

These motors are mostly of small size, developing from 20 to 50 b.h.p. and usually of the two-cycle type. The most noted makers are the Ikegai Iron Works in Tokyo, where they make motors for both land and marine use up to about 500 b.h.p Many foreign-made motors are also in use, the Bolinder motors of 360 b.h.p. being the largest among them.

The Kawasaki Works have the license for constructing Diesel engines of the M.A.N. type, but as yet they have not made any for sea-going craft.

23. The growing demand for auxiliary machinery has induced the establishment of a few special makers, but this tendency is yet in its infancy, and the well-known engine-makers mentioned above do not care to depend upon these establishments. They have therefore purchased licenses to make such auxiliaries as Weir's pumps, Contraflo and Uniflux condensers, Kinetic air pumps, Leblanc pumps, etc. The author believes in the success of the specialization of such an industry as winch-making in the near future, as these can be made of standard patterns and the demand is increasing.

24. In conclusion, it may be said that almost every variety of engines now in actual use in Europe and America can be produced in Japan, not excepting even Diesel engines, and this state of progress is mainly due to the Government protection, although the persevering effort of the builders to turn out the best class of work, and the energetic spirit of the shipowners who favor them with orders of novel type have been most encouraging. The

TABLE I.

SHOWING YEARLY OUTPUT OF MACHINERY, CONSTRUCTED UNDER THE "SHIPBUILDING ENCOURAGEMENT LAW" ACCORDING TO SIZE.

Indicated Horse Power / Date of Completion	Under 1,000		Above 1,000 and under 2,000		Above 2,000 and under 3,000		Above 3,000 and under 4,000		Above 4,000 and under 5,000		Above 5,000 and under 6,000		Above 6,000 and under 7,000		Above 7,000 and under 8,000		Above 8,000 and under 9,000		Above 9,000 and under 10,000		Above 10,000		Total	
	Set.	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.	Set	I. H. P.
1897	1	877																					1	877
1898	1	305					1	3.888															2	4.193
1899			2	2.382					1	4.112													3	6.494
1900			2	3.798	2	4.452																	4	8.250
1901	2	1.380	4	5.270	1	2.495					2	10.517											9	19.662
1902			4	5.531	2	4.645					1	5.448											7	15.624
1903	4	3.057	3	4.726			1	3.832					1	6.780									9	18.395
1904	5	3.894	2	3.272	1	2.438							1	6.503									9	16.107
1905	2	1.105	3	4.093	4	9.796																	9	14.994
1906	4	2.891	6	7.722			1	3.076			1	5.519											12	19.208
1907	5	2.959	1	1.347	2	5.439	2	6.391							1	7.582							11	23.718
1908	2	1.049	1	1.207													3	25.405	2	18.160			8	46.321
1909	2	1.047							1	4.975	3	17.069							2	18.465			8	41.556
1910	1	586	1	1.240							2	10.522											4	12.348
1911	3	1.878									1	5.073									1	21.355	5	28.306
1912			1	1.199			1	3.601	2	9.278	1	5.618	1	6.072									6	25.768
1913															1	7.998					3	34.900	4	42.898
1914	5	4.199	5	7.033							2	10.909									3	33.616	15	55.757
Total	37	25.227	35	48.820	12	29.265	6	20.788	4	18.365	13	70.675	3	19.355	2	15.580	3	25.905	4	36.625	7	89.871	126	400.476

TABLE II.

SHOWING WORKS IN HAND IN VARIOUS ENGINE-WORKS AT THE END OF MAY 1915.

MAKERS	SETS OF ENGINES	I.H.P. OF EACH SET.	TOTAL I.H.P.
MITSUBISHI DOCKYARD AND ENGINE WORKS, NAGASAKI.	1	5,800 *	38.600
	1	5.200	
	4	5.800 **	
	2	2,200	
MITSUBISHI DOCKYARD AND ENGINE WORKS. KOBE.	1	1.200	6.200
	2	2,500	
KAWASAKI DOCKYARD CO	2	6,000	49 350
	1	8,000	
	1	2,500	
	3	5.800	
	2	3,000	
	1	2,000	
	1	1,450	
OSAKA IRON WORKS	1	2,700	63,250
	1	2,000	
	6	5 500	
	1	2.500	
	12	1,850	
	1	850	
URAGA DOCK CO.	5	1,200	6,000
FUJINAGATA DOCKYARD CO.	1	1,200	1.200
HARIMA DOCKYARD CO.	2	850	1,700
TOTAL	52		166,300

* GEARED TURBINES

** GEARED TURBINES FOR TWO SETS, AND RECIPROCATING ENGINES FOR OTHER TWO SETS

TABLE III

SHOWING YEARLY OUTPUT OF MACHINERY, CONSTRUCTED UNDER THE "SHIPBUILDING ENCOURAGEMENT LAW" ACCORDING TO TYPE OF ENGINES.

TYPE OF ENGINES / DATE OF COMPLETION	RECIPROCATING ENGINES				STEAM TURBINES *				COMBINATION SYSTEM				TOTAL					
	SINGLE SCREW		TWIN SCREW		TWIN SCREW		TRIPLE SCREW		TWIN SCREW		TRIPLE SCREW		SINGLE SCREW		TWIN SCREW		TRIPLE SCREW	
	SET	I. H. P.	SET	I. H. P.	SET	I. H. P.	SET	I. H. P.	SET	I. H. P.	SET	I. H. P.	SET	I. H. P.	SET	I. H. P.	SET	I. H. P.
1897	1	877											1	877				
1898	1	305	1	3.888									1	305	1	3.888		
1899	1	1,340	2	5,154									1	1,340	2	5,154		
1900	2	3,798	2	4.452									2	3.798	2	4,452		
1901	5	5.163	4	14,499									5	5.163	4	14.499		
1902	5	8,857	2	6,767									5	8.857	2	6,767		
1903	6	15.863	3	2.532									6	15.863	3	2,532		
1904	7	7.166	2	8.441									7	7,166	2	8,941		
1905	6	8,808	3	6.186									6	8.808	3	6.186		
1906	8	7,487	4	11.721									8	7.487	4	11.721		
1907	8	9.745	3	13,973									8	9.745	3	13,973		
1908	3	2.256	4	34,917			1	9.148					3	2.256	4	34,917	1	9.148
1909	3	6.949	4	25.193			1	9.414					3	6.949	4	25.193	1	9.414
1910	2	1,826	2	10.522									2	1.826	2	10.522		
1911	3	1.878	1	5.073			1	21,355					3	1,878	1	5.073	1	21,355
1912	2	4,800	4	20,968									2	4,800	4	20,968		
1913			1	10,026	·2	21,091					1	11,781			3	31,117	1	11781
1914	10	11.232	4	38,775	1	5,750							10	11.232	5	44,525		
TOTAL	73	98,350	46	223.587	3	26.841	3	39.917			1	11,781	73	98,350	49	250.428	4	51,698

* GEARED TURBINES INCLUDED.

Table IV

Showing output of Machinery, constructed under the "Shipbuilding Encouragemet Law" according to size and makers.

Makers / Indicated Horse Power	Mitsubishi Dockyard and Engine Works		Kawasaki Dockyard Co.		Osaka Iron Works		Ishikawajima Dockyard Co.		Ono Iron Works.		Uraga Dock Co.		Total	
	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.
Under 1,000	3	1,448	5	4,435	27	17,677	1	636	1	531			37	25,227
Above 1,000 and under 2,000	12	17,786	11	14,259	10	14,246	1	1,368			1	1,161	35	48,820
" 2,000 " " 3,000	7	16,877	5	12,388									12	29,265
" 3,000 " " 4,000	2	7,720	4	13,068									6	20,788
" 4,000 " " 5,000	1	4,112	3	14,253									4	18,365
" 5,000 " " 6,000	10	54,349	3	16,326									13	70,675
" 6,000 " " 7,000	2	13,283	1	6,072									3	19,355
" 7,000 " " 8,000	2	15,580											2	15,580
" 8,000 " " 9,000	1	8,144	2	17,761									3	25,905
" 9,000 " " 10,000	4	36,625											4	36,625
" 10,000	4	56,058	3	33,813									7	89,871
Total	48	232,482	37	132,375	37	31,923	2	2,004	1	531	1	1,161	126	400,476

Table V

Showing output of Machinery, constructed under the "Shipbuilding Encouragement Law" according to makers and type of engines.

Makers / Type of Engines		Mitsubishi Dockyard and Engine Works		Kawasaki Dockyard Co.		Osaka Iron Works		Ishikawajima Dockyard Co.		Ono Iron Works.		Uraga Dock Co.		Total.	
		Set	I.H.P.	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.	Set	I.H.P.
Reciprocating Engines	Single Screw	19	40,413	16	25,404	34	28,837	2	2,004	1	531	1	1,161	73	98,350
	Twin Screw	23	126,623	20	93,878	3	3,086							46	223,587
Steam Turbines *	Twin Screw	2	13,748	1	13,093									3	26,481
	Triple Screw	3	39,917											3	39,917
Combination System	Twin Screw														
	Triple Screw	1	11,781											1	11,781
Total		48	232,482	37	132,375	37	31,923	2	2,004	1	531	1	1,161	126	400,476

TABLE VI

TRIAL RESULTS OF TSUSHIMA MARU, TOYOHASHI MARU AND TOYO-OKA MARU.

	BUILDERS	LENGTH B. P.	BREADTH MOULDED	DEPTH MOULDED	GROSS TONNAGE	DIAMETER OF CYLINDERS			STROKE	DIAMETER AND LENGTH OF ROTORS		COOLING SURFACE	BOILERS					PROPELLERS				DATE AND SITE OF TRIAL
						H.P.	I.P.	L.P.		H. P.	L. P.		NO.	DIA.	LENGTH	G. A.	H. S.	DIAMETER	PITCH	EXPANDED SURFACE	NO. OF BLADES	
TSUSHIMA MARU	HULL. RUSSEL, PORT GLASGOW MACHINERY D.W. ROWAN, GLASGOW	445′	58′	34′	6,723.7	S. 20	$33\frac{1}{2}$	56	48				4	14′-3″	11′-6″	217	8,892	S. 15′-6″	17′-6″	71 ф	4	OCT. 1914 SKELMORLIE
						P. 20	$33\frac{1}{2}$	56	48									P. 〃	〃	〃	〃	
TOYOHASHI MARU	KAWASAKI DOCKYARD CO.	445′	58′	34′	7,298.5	S. 21	$33\frac{1}{2}$	56	48			4249	4	14′-3″	11′-6″	220	9,108	S. 16′-0″	18′-9″	82	〃	APR. 1915 KOBE
						P. 21	$33\frac{1}{2}$	56	48									P. 〃	〃	〃	〃	
TOYO-OKA MARU	MISUSBISHI DOCKYARD AND ENGINE WORKS	445′	58′	34′	7,377.9	S.				1′-$2\frac{1}{2}$″ × 14′-4″	2′-6″ × 13′-8″	5240	4	14′-3″	11′-6″	225	9,507	S. 14′-3″	13′-9″	63.3	〃	FEB. 1915 NAGASAKI
						P.				〃	〃							P. 〃	〃	〃	〃	

NO. OF RUNS	SPEED OF SHIP	DRAUGHT			DISPLACEMENT	MIDSHIP SECTION AREA	$\Delta^{\frac{2}{3}} \times \frac{S^3}{I.H.P.}$	$D^{\frac{2}{3}} \times \frac{S^3}{I.H.P.}$	$\frac{I.H.P.}{H.S.}$	$\frac{I.H.P.}{G.A.}$	COAL CONSUMPTION PER I.H.P PER HOUR	REVOLUTIONS PER MINUTE	VACUUM OF CONDENSER	GAUGE PRESSURE.				I.H.P. OR S.H.P.		TEMPERATURE OF STEAM IN DEGREES. F.			SLIP %
		FORE	AFT	MEAN										BOILER	H. P.	I. P.	L. P.	TOTAL	GLAND TOTAL	H. P.	I. P.	L. P	
6	13.68	14′-5″	19′-7″	17′-0″	9103	969	564	256	0.494	20.26		86.9	28.2	S.	194.2	63.1	11.71	2210	4,396				9.19
												88.4	27.3	P.	194.7	66.6	14.42	2,186					
6-3 MILES	14.55	17′-6″	17′-$5\frac{1}{2}$″	17′-$5\frac{3}{4}$″	9585	983	505	232	0.66	27.32	1.404	86.4	27.5	S. 200	199.8	88.7	19.00	3,017	5,930	623	424	268	8.99
												87.2	27.2	P.	200.0	87.2	18.00	2,913		604	271	164	9.80
6-3 MILES	14.54	16′-10″	18′-4″	17′-7″	9650	992	544 †	248 †	0.59	24.95	1.355	116.8	27.8	S. 200.6	182.0		13.83	2,510	5,328				8.21
												118.4	27.7	P.	180.0		12.00	2,814					9.47

† S.H.P. IS TAKEN.

N.B.— TSUSHIMA MARU IS FITTED WITH ORDINARY TRIPLE-EXPANSION ENGINES. TOYOHASHI MARU WITH TRIPLE EXPANSION ENGINES WITH SUPERHEATED STEAM AND TOYO-OKA MARU WITH GEARED TURBINES

question as to when to put a stop to subsidies is always worthy of study, but it is the unanimous opinion among experts that the inefficiency of workmen and the want and costliness of raw materials have to be made good before the subvention is withdrawn altogether.

Paper No. 214

OIL FUEL.

By

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The use of oil fuel for marine purposes comprises essentially the burning of oil in the furnaces of steam boilers. A limited amount, it is true, is consumed in the cylinders of internal combustion engines, and the scope of the latter in marine service will be considered in another paper before this Congress.

But it was tersely stated a few years ago by Prof. Lionel S. Marks of Harvard University that the history of the internal combustion engine has yet to be written. It is being written—with ingenuity, patience and zeal, but with no great progress toward large powers, and the steam-driven motor, with all its limitations, still stands preeminent in the field of power development.

The "Steel Age" and the "Age of Electricity" have only widened the sphere of Steam, on which they depend, and until some predestined genius shall convert the heat of the sun directly into work, or until the "Ray" foretold by Kipling shall really come into conscious being, along with his "cloud piercing search-light", steam boilers are likely to be used in larger units and in multiplying numbers, and oil fuel for marine purposes confined largely to the generation of steam.

OIL DISCOVERY AND PRODUCTION.

The discovery of oil shale in Colorado and Utah, in 1912, has reawakened interest in a valuable paraffin oil, the manufacture of which in the United States, while profitable for a time, early succumbed to the lower price of crude petroleum.

Shale oil has, however, continued to be produced in France and Germany, and especially in Scotland, where in 1913 more than three million tons of shale were distilled, producing over a million and a half barrels of oil, and a very large amount of ammonium sulphate. The beginning of this industry is closely allied with early developments in the production and refining of petroleum, for it was the exhaustion of a petroleum "spring", and later of a special coal supply used for making paraffin oil, that led to the distillation of shale.

In December, 1847, Mr. James Young, a noted chemist of England, was informed of the existence of a spring or seepage of crude oil at Alfreton, Derbyshire, in connection with the working of coal deposits. He experimented with the oil and devised a method of distilling paraffin oil from the crude. The oil "spring" soon went dry, but on the theory that the oil had been produced from the coal by a distillation process in the earth at low temperature, Young set out to produce a paraffin oil from coal by artificial methods. He succeeded with a special gas coal found in West Lothian, and established a profitable business in illuminating oil, the process being based on the famous patent granted to Young in England in 1850 for the low temperature distillation of coal. The process was later patented in America.

The discovery of the oil spring worked by Young was not an isolated case, and we need no other testimony that petroleum was known to the ancients than the references in the Bible, notably that which appears in the XXIX Chapter of Job: "And the rock poured me out rivers of oil". (The name petroleum is, in fact, derived from two Latin words; *petra*, rock, and *oleum*, oil, meaning "rock oil".)

The historic temple of the Ancient Fire-worshippers at Surakhany, on the Apsheron peninsula, near the shores of the Caspian Sea, and not far from Baku, was situated right on the edge of the famous oil fields of Russia, and doubtless the outcroppings of petroleum, as well as the natural gas for supplying the "eternal fires", were known to the devotees who visited this temple many centuries ago. Marco Polo in the 13th century says of the Baku fields, "there is a fountain from which oil springs in great abundance inasmuch as a hundred shiploads

Fig. 1. Oil Spring in Mexico.
(Courtesy Mexican Petroleum Co.)

might be taken from it at one time. This oil is not good to use with food, but is good to burn''.

Oil is spoken of by Herodotus, Plutarch, Pliny, and many other ancient writers.

Still further testimony of the early knowledge of petroleum is furnished by explorers of America who traveled through New York, Pennsylvania and the Middle West in the 18th century, and who reported the burning of crude oil in the religious rites of the Indians, and its use by their medicine men for curative purposes. One of these travelers, Peter Kalm of Russia, even published a map showing the oil springs of Pennsylvania, on his return from a visit to America in 1748.

Thus, outcroppings of rock oil were of common repute in various parts of the world when Young began work on the Alfreton spring, and, not only that, but paraffin had been produced from bitumen some twenty years before, and kerosene or ''coal oil'' had already been distilled from coal in both Germany and France. But the principal uses for petroleum were for rough lubricating purposes, rude torches and for alleged ''cures'' more or less on the patent medicine basis, so that Young's achievement in producing paraffin oil as an illuminant on a commercial basis is of historic interest, as it pointed the way for the profitable utilization of petroleum and stimulated the search for oil in greater quantities.

In 1854 the Pennsylvania Rock Oil Company was organized in New York for the avowed purpose to ''raise, procure, manufacture and sell Rock Oil'', and a report on a sample of oil from Venango Co., Pa., made for the company by Professor B. Silliman, of Yale University, in April, 1855, not only marked the American professor of chemistry as a widely-read and well-informed student of the known oil-fields of the world, but gave a fractional distillation of petroleum which clearly indicated its marvelous value to mankind. But the embryonic industry languished until some of the more pertinacious promoters of the oil company formed the Seneca Oil Company and started digging operations under the supervision of ''Colonel'' E. L. Drake, on some land leased from the parent company.

Then occurred one of those inspired applications of old ideas to new problems which convert comparative failure to

success with revolutionary effects. Artesian wells had been drilled to considerable depths, some for the purpose of obtaining salt. One of these, 400 feet deep, owned by Kier of Pittsburgh, accidentally produced a limited amount of petroleum which was bottled and widely sold for medicinal purposes. This appears to have suggested to Mr. George H. Bissel, a promoter of the original oil company, and an enthusiastic backer of the well-digging scheme, to apply the artesian-well drilling idea to the search for oil.

Drake at once saw its possibilities and with much ingenuity applied the then untried method of sinking an iron pipe through the super strata of earth to bed rock and operating the drill through the pipe, and in August, 1859, on Oil Creek, Pa., he "struck oil" at a depth of 69 feet.

Although a small trade in petroleum had existed for many years at Baku, and considerable oil had been produced in Roumania from hand-dug wells, the real oil-producing and refining industry started when oil commenced to flow from Drake's well, and the production went forward with a tremendous impulse, ever increasing in amount from that day to this. The statistics of the inserted table were compiled by the U. S. Geological Survey, and are reproduced from their published reports.

USE OF OIL AS FUEL.

The decade following the advent of Drake's well is marked by considerable activity in inventions of methods for utilizing oil as fuel for power purposes, and its adaptability to marine usage is emphasized by the experiments of the United States Navy under Commodore Isherwood, and of the British Admiralty under Admiral Selwyn. In the Baku region also, on the Caspian Sea, and on the Volga, where, owing to the character of the oil and the cruder methods of refining, a large proportion of the oil was available for fuel, the subject received serious attention; though, previous to 1870 much of the *astatki* (or "leavings") was disposed of by burning in open pits. During this period all the Russian wells were hand dug, the deepest being not over fifty feet below the surface; but a new era began in '71 with the drilling of the first well on the Balakhany plateau and the appearance of the first Baku "gushers". In

1874, the Russian Government adopted oil fuel for all vessels of the Caspian Fleet, and the year following, Robert and Ludwig Nobel (brothers of the celebrated engineer and chemist who founded the Nobel Prizes), lent a great impetus to the Russian oil industry by improving the refining methods, building pipe lines, tank cars, tank vessels, etc., and barges for carrying oil on the Volga River.

The remote position of the Baku fields and the lack of really adequate transportation facilities, however, greatly limited the introduction of Russian fuel oil to other countries, except possibly in Persia. On the other hand, American oil was very valuable for refining, and while a considerable amount was devoted to fuel purposes, and many types of steam-atomizing oil burners came to be used in regions near the oil fields as the production gradually spread from Pennsylvania to West Virginia, Ohio, Indiana, etc., still the bulk of the oil went into the manufacture of illuminants, lubricating oils, paraffin, etc., and practically none was available for fuel for marine installations.

This was the situation in 1893, when Colonel Nabor Soliani of the Royal Italian Navy presented his comprehensive paper, "Oil Fuel for Marine Purposes", before the Division of Marine and Naval Engineering and Naval Architecture of the International Engineering Congress held in connection with the World's Columbian Exposition at Chicago. The high cost of coal in Italy and the comparative accessibility to the Baku oil regions were factors which led to early experiments with oil by the Italian Navy, and the advantages of the use of what Colonel Soliani called "naphtha refuse" and the successful application of various types of "pulverizers" (all of which were of the steam-atomizing type) were clearly pointed out in this able paper.

Outside of Russia and the few points where Baku oil was obtainable and excepting in a very limited field in America, "oil fuel", as such, was not in evidence at this period. It was even currently reported, with no great exaggeration, that the Standard Oil Company burned coal under their boilers and not oil.

Such was the state of things, when in June, 1901, Captain A. F. Lucas drilled his sensational well near Beaumont, Texas—known as Spindle-top. Elsewhere in this paper, I am fortunate

Fig. 2. Spindle-Top.
(Courtesy of Capt. Lucas.)

in being able to give a brief description by Captain Lucas himself of the discovery of this wonderful oil field.

Spindle-top marks a distinct epoch in the history of oil fuel. The tremendous capacity of the "gusher" (over 100,000 barrels a day), a character of oil ideal for fuel purposes, the proximity to the coast, facilitating easy transportation, and the resulting "boom" in drilling which still further increased the supply, all combined to place "fuel oil" on a basis of permanency which it has held for fifteen years, and which today seems to be more than ever assured.

Coincident with the development of the Texas oil field, and largely on account of it, the California fields, which had already had a healthy growth, forged rapidly ahead, and in 1903 this state assumed the position of the first of the oil-producing states, which distinction it has since held unchallenged. California oil is largely of a character which makes it available for fuel, so that with the Beaumont "gushers" to supply the East and California to supply the West, oil fuel became the all-absorbing subject among power users in America, and the interest rapidly spread to other countries. Everybody who had an oil burner to sell began to haunt the presence of the prospective user and to claim the usual "ten percent" superiority over his competitors—new designs and new inventions of "burners" sprang into existence—oil fuel installations began to be made on a large scale and the importance of the movement led some of the large manufacturing and engineering companies to make careful investigations and prosecute valuable experimental studies of methods of oil burning. What is especially noteworthy, interest in oil as a fuel revived in marine circles, and oil fuel began to be used aboard ship. A considerable number of notable marine installations were made at this time; among others, several by the New York Shipbuilding Company under the direction of one of the pioneers of the art of oil burning on shipboard in this country, Mr. Luther D. Lovekin. These vessels were operated on the Pacific Coast, and were very successful and the objects of much comment.

In 1901 the late Rear-Admiral George W. Melville, U. S. N., then Engineer-in-Chief of the Navy, impressed by the great output of oil at Spindle-top, and convinced that oil was des-

tined to play an important part in military achievement, appointed a special board of naval officers, under the able direction of Commander (now Rear-Admiral) John R. Edwards, to investigate the "relative value of oil and coal as a fuel for naval purposes". The report of the exhaustive investigation of the subject by this Board, published in 1904, has long been considered the most valuable and complete treatise of its kind.

Undoubtedly the activity in the fuel-oil field resulting from the great production of oil in Texas and California during the five years following the discovery at Spindle-top, together with the attention given the subject by our navy, reawakened the active interest of the British Admiralty, to whom we are indebted for inaugurating the present wide-spread use of the mechanical atomizer.

WHAT IS FUEL OIL?

The origin of petroleum can hardly be considered an important matter to prospective users of fuel oil. The question whether it is animal, vegetable or mineral, or all three (which seems likely), organic or inorganic, belongs rather to the province of the geologist to decipher. Those interested may refer to the scientific papers on this topic, published in the Transactions of the American Institute of Mining Engineers for 1914, and I understand also that a paper is to be presented at the Fourth International Petroleum Congress at San Francisco, 1915, by Dr. David T. Day, of the U. S. Bureau of Mines, which will settle the controversy—probably. But the available supply of oil and prospects of its continuance are of prime importance to the vessel owner who contemplates using oil as a fuel.

Let us consider then: In the first place, what is "fuel oil"? We are told that petroleum consists of very many combinations of carbon and hydrogen or hydro-carbons, which while they may be entirely simple to the chemist, seem extremely complicated and abstruse to the lay mind, as for example, Propane ($CH_3.CH_2.CH_3$) or Dimelhylpropylmethane $(CH_3)_2.\ CH\ (CH_2.\ CH_2.\ CH_3)$ or Hentriacontane ($C_{32}\ H_{66}$).

How much of this intricate product may we expect to be turned over for use as "fuel oil"? I have asked Doctor Day to answer this question, and am indebted to him for the following statement:

"From the standpoint of the petroleum trade, fuel oil, in general, includes all oils which are not saleable for some other special purpose at a higher price than that which prevails for oils to be sold as fuel oils, or to be burned under boilers. From the trade point of view, it also includes special distillates which are sold as Diesel oils. It does not include various distillates burned for power purposes, such as gasolene, naphtha, motor spirits, and various kerosene distillates. The actual amount of oil devoted to fuel purposes varies continually with the condition of the production of crude petroleum. During the time of flush production, such as has existed in the Oklahoma fields during the past year due to the extraordinary production in the Cushing field, a great deal of crude petroleum is sold as fuel oil on account of the necessity of disposing of it when no better market is available. The use of such oil is not advisable for fuel purposes, not only because it contains valuable gasolene and kerosene, but these contents so lower the flashing point of the fuel oil as to make it open to the objections to gasolene stored in a confined space, as on a battleship, where the vapor is liable to produce explosions on contact with air.

"Until the last twelve months, much of the production of California crude oil was sold for fuel purposes practically as it came from the well. Within the last year, however, the practice of topping off the valuable gasolene and kerosene in a comparatively small proportion of California oils has so increased that not more than 25 percent of the fuel oil of California is now crude oil. In States other than California and Oklahoma, and to a slight extent, Texas, fuel oils consist chiefly of the least valuable distillates and some residuum. The distillates of such low value as to be sold for fuel oil are usually the products distilling off after kerosene, and those too heavy for burning in lamps and also too thin to be used as lubricating oils. Such oils generally have the name of gas oils, and are more valuable for use as gas oils than for fuel purposes, but the market for gas oils is easily over-supplied, and the surplus goes for fuel oil.

"The annual production of petroleum in the United States is about 266,000,000 barrels in round numbers, of which at least 100,000,000 barrels is consumed as fuel. This proportion will hold fairly well for the petroleum production of the world, that is, about 2/5 of the world's production may be considered 'fuel oil'. In regions such as the East Indies, the petroleum is to a large extent too valuable for use as fuel. This is offset by Mexico and Russia, where the use of residuum and even crude oil for fuel purposes is very general, and exceeds the average proportion."

DISTRIBUTING POINTS AND STORAGE AT SHORE STATIONS.

However great the incentive may be for vessel owners to adopt oil as fuel, there will be no universal use of it, as opposed to coal, until the supply is assured and distribution points, or

Fig. 3. Storage and Distributing Station, Mexican Petroleum Co., Tampico, Mexico.

fueling stations, are spread over the earth, where steamships may replenish their bunkers. In Naval service the wonderful advantage which oil possesses of ability to "fuel" ships at sea by hauling a hose aboard from a tanker at safe towing distance, will be an added reason for the use of oil, and will facilitate the operation of the fleets in any waters. The merchant ship must, however, depend upon shore stations.

I am indebted to officials of the larger oil companies for the following instructive list of localities where fuel is available for ship use. In the limited time, this could not be made complete. These stations are equipped with large storage tanks, frequently of a capacity of 55,000 barrels of oil each, with ample pumping capacity and pipe line facilities leading from the tanks along the length of the docks or vessel berths on the water fronts.

The tankers from the oil fields tie up at the docks and discharge cargo to the tanks, either by means of their own pumps or, usually, the shore pumps. When vessels apply for fuel oil, the shore pumps put the oil into the bunkers on shipboard through the same pipes used for unloading the tankers. In many cases, also, the storage tanks are supplied by tank cars, or oil from the cars may be put directly on board the vessels. The tank cars, storage tanks and cargo holds of the tankers are provided with heating coils for heating the heavier oils.

Partial List of Oil Distributing Stations in the United States (Including Some Now Building).

Place	Oil Company	Storage Capacity Barrels of 42 Gallons
Aberdeen, Wash.	Standard Oil Co. of California	34,000
Alameda Point, Cal.	Associated Oil Co.	37,500
Aransas Pass, Tex.	The Texas Co.	55,000
Astoria, Ore.	Standard Oil Co. of California	10,000
Avon (Suisun Bay), Cal.	Associated Oil Co.	1,000,000
Baltimore, Md.	Interocean Oil Co.	220,000
Baltimore, Md.	Standard Oil Co. of N. Jersey	50,000
Baltimore, Md.	The Texas Company	55,000
Baton Rouge, La.	Standard Oil Co. of Louisiana	
Bayonne, N. J. (New York Harbor)	Standard Oil Co. of N. Jersey	300,000
Bayonne, N. J.	The Texas Company	276,000
Bellingham, Wash.	Standard Oil Co. of California	8,500

Partial List of Oil Distributing Stations in the United States—Continued.

Place	Oil Company	Storage Capacity Barrels of 42 Gallons
Boston, Mass.	Mexican Petroleum Co.	200,000
Boston, Mass.	Standard Oil Co. of New York	50,000
Boston, Mass.	United States Navy	50,000
Carteret, N. J. (Near New York)	Interocean Oil Co.	100,000
Chester, Pa.	Interocean Oil Co.	120,000
Charleston, S. C.	Standard Oil Co. of N. Jersey	15,000
Charleston, S. C.	The Texas Company	104,000
Charleston, S. C.	United States Navy	35,000
Cristobal, Panama	The Texas Company	110,000
El Segundo, Cal.	Standard Oil Co. of California	100,000
Eureka, Cal.	Standard Oil Co. of California	35,000
Galveston, Texas	The Texas Company	110,000
Gaviota, Cal. (Santa Barbara Channel)	Associated Oil Co.	120,000
Guantanamo Bay, Cuba	United States Navy	212,000
Honolulu, H. I.	Associated Oil Co.	102,000
Honolulu, H. I.	Standard Oil Co. of California	100,000
Jacksonville, Fla.	Standard Oil Co. of Kentucky	50,000
Jacksonville, Fla.	The Texas Company	55,000
Ketchikan, Alaska	Standard Oil Co. of California	38,000
Key West, Fla.	Standard Oil Co. of Kentucky	50,000
Key West, Fla.	U. S. Navy	35,000
Linnton, Oregon (9 miles from Portland)	Associated Oil Co.	173,000
Marcus Hook, Del.	Sun Oil Company	500,000
Mare Island, Cal.	United States Navy	100,000
Melville Station, R. I.	United States Navy	85,000
Mobile, Ala.	The Texas Company	25,000
Monterey, Cal.	Associated Oil Co.	340,000
Morgan City, La.	The Texas Company	55,000
New Orleans, La.	Mexican Petroleum Co.	400,000
New Orleans, La.	The Texas Company	124,000
New York, N. Y.	Mexican Petroleum Co.	500,000
New York, N. Y.	Standard Oil Co. of New York	100,000
Norfolk, Va.	The Texas Company	138,000
Norfolk, Va.	United States Navy	185,000
Oakland, Cal.	Standard Oil Co. of California	10,000
Panama	Mexican Petroleum Co.	100,000
Pearl Harbor, Hawaii	United States Navy	235,000
Philadelphia, Pa.	The Texas Company	334,000
Point Breeze, Pa. (Philadelphia)	Atlantic Refining Co.	500,000

Partial List of Oil Distributing Stations in the United States—Continued.

Place	Oil Company	Storage Capacity Barrels of 42 Gallons
Point Wells, Wash. (13 miles from Seattle)	Standard Oil Co. of California	200,000
Port Arthur, Texas	The Texas Company	Practically Unlimited
Port Chalmette, La.	Standard Oil Co. of Louisiana	
Port Costa, Cal. (Carquinez Strait)	Associated Oil Company	480,000
Portland, Me.	Mexican Petroleum Co.	200,000
Portland, Me.	Standard Oil Co. of New York	30,000
Portland, Ore.	Standard Oil Co. of California	85,000
Port Townsend, Wash.	Standard Oil Co. of California	27,000
Providence, R. I.	Mexican Petroleum Co.	100,000
Providence, R. I.	Standard Oil Co. of New York	10,000
Providence, R. I.	The Texas Company	253,000
Puget Sound, Wash.	United States Navy	100,000
Richmond, Cal.	Standard Oil Co. of California	200,000
Sacramento, Cal.	Associated Oil Co.	5,100
Sabine Pass, Texas	Sun Oil Company	250,000
San Diego, Cal.	Standard Oil Co. of California	34,000
San Diego, Cal.	United States Navy	100,000
San Francisco, Cal.	Associated Oil Co.	97,800
San Francisco, Cal.	Standard Oil Co. of California	15,000
San Pedro (East), Cal.	Standard Oil Co. of California	35,000
Seattle, Wash.	Standard Oil Co. of California	90,000
Stockton, Cal.	Associated Oil Company	5,200
Tacoma, Wash.	Standard Oil Co. of California	34,000
Tampa, Fla.	Standard Oil Co. of Kentucky	70,000

Fuel oil is obtainable from distributing stations of the Imperial Oil Company, Limited, at—

Fort William, Ontario.
Halifax, N. S.
Montreal, Quebec.
Prince Rupert, B. C.
Quebec, Quebec.
Sarnia, Ontario.
Toronto, Ontario.
Vancouver, B. C.
Victoria, B. C.

Oil can also be obtained at many European and Asiatic ports and also in South America, but my efforts to secure a list of these stations have met with so little success, and the list is so incomplete, that I have concluded to omit it altogether.

Fig. 4A. Storage and Distributing Station, Texas Company, Bayonne, N. J.

WORLD'S TOTAL MARKETED PRODUCTION OF CRUDE PETROLEUM, 1857-1914, BY YEARS AND BY COUNTRIES, IN BARRELS OF 42 GALLONS.

	Roumania.	United States.	Italy.	Canada.	Russia.	Galicia.	Japan.	Germany.	India.	Dutch East Indies.	Peru.	Mexico.	Trinidad.	Egypt.	Other countries.	Total
1857	1,977	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1,977
1858	3,560	......	......	......	......	......	......	......	......	......	......	......	......	......	......	3,560
1859	4,349	2,000	......	......	......	......	......	......	......	......	......	......	......	......	......	6,349
1860	8,542	500,000	36	......	......	......	......	......	......	......	......	......	......	......	......	508,578
1861	17,279	2,113,609	29	......	......	......	......	......	......	......	......	......	......	......	......	2,130,917
1862	23,198	3,056,690	29	11,775	......	......	......	......	......	......	......	......	......	......	......	3,091,692
1863	27,943	2,611,309	58	82,814	40,816	......	......	......	......	......	......	......	......	......	......	2,762,940
1864	33,013	2,116,109	72	90,000	64,586	......	......	......	......	......	......	......	......	......	......	2,303,780
1865	39,017	2,497,700	2,265	110,000	66,542	......	......	......	......	......	......	......	......	......	......	2,715,524
1866	42,534	3,597,700	992	175,000	83,052	......	......	......	......	......	......	......	......	......	......	3,899,278
1867	50,838	3,347,300	791	190,000	119,917	......	......	......	......	......	......	......	......	......	......	3,708,846
1868	55,369	3,646,117	367	200,000	88,327	......	......	......	......	......	......	......	......	......	......	3,990,180
1869	58,533	4,215,000	144	220,000	202,308	......	......	......	......	......	......	......	......	......	......	4,695,985
1870	83,765	5,260,745	86	250,000	204,618	......	......	......	......	......	......	......	......	......	......	5,799,214
1871	90,030	5,205,234	273	269,397	165,129	......	......	......	......	......	......	......	......	......	......	5,730,063
1872	91,251	6,293,194	331	308,100	184,391	......	......	......	......	......	......	......	......	......	......	6,877,267
1873	104,036	9,893,786	467	365,052	474,379	......	......	......	......	......	......	......	......	......	......	10,837,720
1874	103,177	10,926,945	604	168,807	583,751	149,837	......	......	......	......	......	......	......	......	......	11,933,121
1875	108,569	8,787,514	813	220,000	697,364	158,522	4,566	......	......	......	......	......	......	......	......	9,977,348
1876	111,314	9,132,669	2,891	312,000	1,320,528	164,157	7,708	......	......	......	......	......	......	......	......	11,051,267
1877	108,569	13,350,363	2,934	312,000	1,800,720	169,792	9,560	......	......	......	......	......	......	......	......	15,753,938
1878	109,300	15,396,868	4,329	312,000	2,400,960	175,420	17,884	......	......	......	......	......	......	......	......	18,416,761
1879	110,007	19,914,146	2,891	575,000	2,761,104	214,800	23,457	......	......	......	......	......	......	......	......	23,601,405
1880	114,321	26,286,123	2,035	350,000	3,001,200	229,120	25,497	9,310	......	......	......	......	......	......	......	30,017,606
1881	121,511	27,661,238	1,237	275,000	3,601,441	286,400	16,751	29,219	......	......	......	......	......	......	......	31,992,797
1882	136,610	30,349,897	1,316	275,000	4,537,815	330,076	15,549	58,025	......	......	......	......	......	......	......	35,704,288
1883	139,486	23,449,633	1,618	250,000	6,002,401	365,160	20,473	26,708	......	......	......	......	......	......	......	30,255,479
1884	210,667	24,218,438	2,855	250,000	10,804,577	408,120	27,923	46,161	......	......	......	......	......	......	......	35,968,741
1885	193,411	21,858,785	1,941	250,000	13,924,596	465,400	29,237	41,360	......	......	......	......	......	......	......	36,764,730
1886	168,606	28,064,841	1,575	584,061	18,006,407	305,884	37,916	73,864	......	......	......	......	......	......	......	47,243,154
1887	181,907	28,283,483	1,496	525,655	18,367,781	343,832	28,645	74,284	......	......	......	......	......	......	......	47,807,083
1888	218,576	27,612,025	1,251	695,203	23,048,787	466,537	37,436	84,782	......	......	......	......	......	......	......	52,164,597
1889	297,666	35,163,513	1,273	704,690	24,609,407	515,268	52,811	68,217	94,250	......	......	......	......	......	......	61,507,095
1890	383,227	45,823,572	2,998	795,030	28,691,218	659,012	51,420	108,296	118,065	......	......	......	......	......	......	76,632,838
1891	488,201	54,292,655	8,305	755,298	34,573,181	630,730	52,917	108,929	190,131	......	......	......	......	......	......	91,100,347
1892	593,175	50,514,657	18,321	779,753	35,774,504	646,220	68,901	101,404	242,284	......	......	......	......	......	......	88,739,219
1893	535,655	48,431,066	19,069	798,406	40,456,519	692,669	106,384	99,390	298,969	600,000	......	......	......	......	......	92,038,127
1894	507,255	49,344,516	20,552	829,104	36,375,428	949,146	171,744	122,564	327,218	688,170	......	......	......	......	......	89,335,697
1895	575,200	52,892,276	25,843	726,138	46,140,174	1,452,999	141,310	121,277	371,536	1,215,757	......	......	......	......	......	103,662,510
1896	543,348	60,960,361	18,149	726,822	47,220,633	2,443,080	197,082	145,061	429,979	1,427,132	47,536	......	......	......	......	114,159,183
1897	570,886	60,475,516	13,892	709,857	54,399,568	2,226,368	218,559	165,745	545,704	2,551,649	70,831	......	......	......	......	121,948,575
1898	776,238	55,364,233	14,489	758,391	61,609,357	2,376,108	265,389	183,427	542,110	2,964,035	70,905	......	......	......	......	124,924,682
1899	1,425,777	57,070,850	16,121	808,570	65,954,968	2,313,047	536,079	192,232	940,971	1,795,961	89,166	......	......	......	......	131,143,742
1900	1,628,535	63,620,529	12,102	913,498	75,779,417	2,346,505	866,814	358,297	1,078,264	2,253,355	274,800	......	......	......	......	149,132,116
1901	1,678,320	69,389,194	16,150	756,679	85,168,556	3,251,544	1,110,790	313,630	1,430,716	4,013,710	274,800	......	......	......	20,000	167,424,089
1902	2,059,935	88,766,916	18,933	530,624	80,540,044	4,142,159	1,193,038	353,674	1,617,363	2,430,465	286,725	......	......	......	26,000	181,965,876
1903	2,763,117	100,461,337	17,876	486,637	75,591,256	5,234,475	1,209,371	445,818	2,510,259	5,770,056	278,092	......	......	......	36,000	194,804,294
1904	3,599,026	117,080,960	25,476	552,575	78,536,655	5,947,383	1,419,473	637,431	3,385,468	6,508,485	345,834	220,653	......	......	40,000	218,299,419
1905	4,420,987	134,717,580	44,027	634,095	54,960,270	5,765,317	1,472,804	560,963	4,137,098	7,849,896	447,880	320,379	......	......	30,000	215,361,296
1906	6,378,184	126,493,936	53,577	569,753	58,897,311	5,467,967	1,710,768	578,610	4,015,803	8,180,657	536,294	1,097,264	......	......	30,000	214,010,124
1907	8,118;207	166,095,335	59,875	788,872	61,850,734	8,455,841	2,001,838	756,631	4,344,162	9,982,597	756,226	1,717,690	......	......	30,000	264,958,008
1908	8,252,157	178,527,355	50,966	527,987	62,186,447	12,612,295	2,070,145	1,009,278	5,047,038	10,283,357	1,011,180	3,481,610	169	......	30,000	285,089,984
1909	9,327,278	183,170,874	42,388	420,755	65,970,350	14,932,799	1,889,563	1,018,837	6,676,517	11,041,852	1,316,118	2,488,742	57,143	......	20,000	298,373,216
1910	9,723,806	209,557,248	50,830	315,895	70,336,574	12,673,688	1,930,661	1,032,522	6,137,990	11,030,620	1,330,105	3,332,807	142,857	......	20,000	327,615,603
1911	11,107,450	220,449,391	74,709	291,096	66,183,691	10,519,270	1,658,903	1,017,045	6,451,203	12,172,949	1,368,274	14,051,643	285,307	9,150	45,000	345,685,081
1912	12,976,232	222,935,044	53,778	243,336	68,019,208	8,535,174	1,671,405	1,031,050	7,116,672	10,845,624	1,751,143	16,558,215	436,805	205,905	105,000	352,484,591
1913	13,554,768	248,446,230	47,256	228,080	62,834,356	7,818,130	1,942,009	995,764	7,930,149	11,966,857	2,133,261	25,902,439	503,616	94,635	270,000	384,667,550
1914	12,826,579	265,762,535	39,548	214,805	67,020,522	5,033,350	2,738,378	995,764	8,000,000	12,705,208	1,917,802	21,188,427	643,533	777,038	620,000	400,483,489
Total	117,982,474	3,335,457,140	802,229	23,493,610	1,622,233,845	131,873,601	27,051,158	12,965,569	73,979,919	138,278,392	14,306,972	90,359,869	2,069,430	1,086,728	1,322,000	5,593,262,936
Per cent	2.11	59.63	0.01	0.42	29.00	2.36	0.48	0.23	1.32	2.47	0.26	1.62	0.04	0.02	0.03	100.00

OIL TANKERS.

Should further proof be necessary of the wide and ever increasing use of oil fuel and the possibilities of obtaining it at points remote from the oil fields, it may be found in the following list of oil tankers of the various nations. This list was prepared for me through the courtesy of Mr. W. A. Thompson, Manager of the Marine Department of the Texas Company, and is corrected to July 20, 1915. Other tank ships for carrying oil are now building. These modern vessels are equipped with the many devices which experience has demanded, for rapid filling and discharge through pipe lines, safe storage (many of them arranged to carry different grades of oil separately stored in the same cargo), swash plates, heating coils for heavy oils, provision for expansion of the oil due to temperature changes, and adequate ventilation of tanks, ingenious arrangements of valves and manifolds to simplify handling, measuring devices, etc., so that the carrying of oil in vessels is to-day decidedly a scientific business. Many of these tankers are still burning coal, but the rapid development of the fuel-oil industry is leading to the conversion of the tankers to oil burning.

Oil Tankers.

Flag	Number of Vessels	Capacity—Barrels of 42 U.S. Gallons
American	158	6,190,135
British	177	8,888,631
German	22	1,263,214
Dutch	41	800,831
Norwegian	9	521,785
Mexican	4	121,190
Argentinian	3	42,619
Italian	3	67,500
Egyptian	1	
Cuban	2	32,976
French	7	270,547
Japanese	6	211,785
Greek	2	50,952
Danish	3	26,904
Roumanian	1	34,523
Portuguese	1	7,857
Spanish	1	5,357
Russian	2	42,143
Belgian	11	304,405

Fig. 4B. Oil Tankers Loading at Tampico.
(Courtesy Mexican Petroleum Co.)

COMPARATIVE COST OF OIL FUEL.

The question whether or not it "pays" to use oil depends on many things. There may be reasons which make its adoption imperative at practically any cost—certain military advantages for instance, such as smoke prevention, speed of vessel, etc.,—but the merchant owner will be influenced by:

(1) Comparative cost with coal, wood or other fuel, delivered on board.

(2) Relative heat value of these fuels.

(3) Relative capacity and efficiency in steam production. This may result in running natural draft instead of forced draft, thus saving the cost of installing and operating blowers or in the installation of less boiler power.

(4) Expense of fitting up for oil, including suitable storage provision on the vessel.

(5) Saving in labor cost due to reduction in number of firemen, elimination of coal passers and the expense of removal of ashes.

(6) Increased life of the boilers and lower maintenance charges, both in the fire and engine rooms and hull of vessel.

(7) Increased bunker capacity and longer steaming radius, or otherwise, on fixed routes between fueling points, saving in dead weight and cargo space by carrying only sufficient oil for the trip.

(8) Time saved on voyage due to steadier steam pressure, and possibly time saved in fueling ship.

Coal may be figured at 42 cubic feet of bunker space per ton and oil at 36 to 40, according to the gravity. Thus, there is a saving of approximately 10% in space in carrying the same weight of oil, while pound for pound more than 40% more steam will be produced with oil—so that there is an increase of approximately 40% in steaming radius for the same weight of oil or nearly 55% for the weight of oil carried in the same bunker space, or on the other hand, a saving of over 35% of bunker space or about 30% in weight for the same steaming radius.

It will be evident that while the cost of the fuel is important, it is not paramount, and must be considered only in connection with the whole general scheme.

Statements of comparative values of oil versus coal, therefore, while extremely common are often misleading. We may, however, by making some reasonable assumptions derive figures of more or less interest to the prospective user of oil. Assuming, therefore, that boiler capacity with oil is at least equal to that with coal; that boiler efficiency in every-day running will be in the ratio of 68 for coal and 75 with oil, and that the coal used for marine purposes will contain 14,400 B. T. U. per pound and that the oil will contain 18,600 B. T. U. per pound and weigh 7.88 pounds per gallon (18° Baumé); that the coal is sold by the ton of 2240 pounds and the oil by the U. S. gallon, or by the standard barrel of 42 gallons, we shall have the following equation when the cost of producing steam with oil equals the cost of producing the same steam with coal:

$$A \times 18{,}600 \times 788 \times 75 = \frac{B}{100} \times 14{,}400 \times 2240 \times 65$$

or

$$A = 1.907\ B$$

Where A = cost of coal in dollars per ton, and B = cost of oil in cents per gallon.

Thus, approximately, when the cost of coal in dollars per ton is double the cost of oil in cents per gallon, the fuel costs of producing steam will be equal. Mr. Walter M. McFarland is the first to point out this simple relationship in the cost of producing steam by coal and oil.

In round numbers, as a steam producer, a pound of oil is equal to a pound and a half of coal, or approximately one ton of coal is equal to four-and-a-half barrels of oil—or to quote another approximate but handy rule, one ton of coal equals 200 gallons of oil.

I am indebted to Mr. A. S. Hebble, Superintending Engineer of the Atlantic Coast Lines of the Southern Pacific R. R. Co. (Morgan Line), who has had a valuable experience in fitting out for oil fuel and operating vessels with Mexican crude oil, for the following comparison of results obtained, on the S. S. "El Norte", in actual operation, first with coal and later with oil as fuel:

"S. S. "El Norte", general dimensions:

Length	405′ - 0″
Beam	48′ - 0″
Depth	33′ - 9″
Displacement	7600 tons

"The vessel is fitted with a vertical, inverted, three-cylinder, three-crank, triple-expansion, surface-condensing engine with cylinders 32″ — 52″ — 84″ x 54″ stroke, and three double-ended Scotch marine boilers, 13′ - 10″ in dia. by 21′ - 2″ long, built for a working pressure of 180 lbs. per square inch. Each boiler contains 6 corrugated furnaces, 42¾″ inside diameter. Each furnace is fitted with one fuel oil burner operated in connection with mechanical atomization system under natural draft. Each boiler contains 3570 sq. ft. of heating surface.

"The number of crew in the fireroom using coal was 12 firemen and 6 coal passers. The number of crew in the fireroom using oil is 6 firemen and 3 wipers.

"**Fuel Analyses:**

"The following analyses show the average fuels on which this report is based:

Coal.

Moisture	0.53%
Ash	9.22%
Sulphur	1.42%
Volatile Com. Matter	19.90%
Fixed Carbon	70.35%
B. T. U. per lb.	14367.0

Mexican Crude Oil.

Specific Gravity at 70 Deg. F.	0.9850
Baumé Gravity at 70 Deg. F.	12.13
Flash Point, Deg. F.	120.
Water	.60%
B. T. U. per lb.	18191.0

"The average performance of the vessel for a period of 10 consecutive voyages, operating under the same general conditions in the same trade, using both coal and Mexican crude oil is as follows:

Using Coal as Fuel.

Voyage No.	Total time at Sea Hrs.	Avg. Rev.	Total H. P.	Total Coal Sht. Tons	Lbs. of Coal per H.P. per Hr.
225	271.62	67.55	3660	747	1.502
226	276.13	64.50	3255	764	1.698
227	289.95	61.25	2860	690	1.666
228	271.93	66.05	3455	712	1.518
229	265.19	67.65	3675	769	1.576
230	300.30	62.60	3023	741	1.631
231	271.47	66.40	3504	755	1.586
232	275.87	67.45	3645	828	1.650
233	274.00	66.80	3558	808	1.660
234	282.45	66.90	3570	860	1.704
Average	277.89	65.72	3420.5	767.4	1.619

Using Mexican Crude Oil as Fuel.

Voyage No.	Total Time at Sea Hrs.	Avg. Rev.	Total H. P.	Total Oil Gals.	Bbls. of Oil (42 Gals.)	Lbs. of Oil per H. P. per Hr.
237	269.36	67.65	3675	148,400	3533.3	1.234
238	269.61	66.75	3550	123,900	2950.0	1.064
239	269.95	66.85	3560	118,000	2809.5	1.011
240	273.63	67.75	3685	129,819	3090.9	1.059
241	268.48	68.20	3750	138,578	3299.5	1.133
242	270.23	67.95	3715	142,173	3385.1	1.164
243	269.55	67.95	3715	126,946	3022.5	1.042
244	271.05	68.35	3775	147,781	3518.6	1.188
245	272.27	66.65	3535	122,410	2914.5	1.045
246	273.45	68.25	3760	142,000	3380.9	1.135
Average	270.76	67.64	3672	134,000.7	3190.5	1.108

NOTE:—Above calculations based on oil weighing 8.22 lbs. per gallon.

"It will be noted from the above figures that the running time and average revolutions of the vessel are much more uniform when using oil than when using coal. This condition would be more particularly marked but for the fact that the vessel is operated on schedule and not at the maximum speed. It is possible, however, with oil fuel to obtain maximum speed continuously, whereas with coal there is a perceptible falling off in speed due to adverse steaming conditions, cleaning fires and excessive temperature in the fireroom".

Mr. Hebble has also given me the following statement relative to cost of fitting out for oil, maintenance charges and the saving in ship's crews when operating with oil:

"The approximate cost of converting a coal burning vessel to use oil, including pumps, piping, heaters, burners, etc., varies with the arrangement, horse-power and trade that the vessel is engaged in. Ordinarily, I should say that a coast-wise vessel of 2000 H.P. would cost between $30,000.00 and $40,000.00, and a similar vessel of 4000 H.P. would cost between $40,000.00 and $50,000.00. This includes structural changes.

"The approximate cost of fitting a fuel-oil burning installation in a new vessel in the coastwise trade also depends on the conditions noted above, and I should say that for a 2000 H.P. vessel the cost would be $20,000.00 to $25,000.00

"The difference in crew as between an oil and coal burning vessel of 1500-2000 H.P. would be about as follows:

Required for coal—6 firemen, 6 coal passers—12 men.

Required for oil—3 firemen, 2 wipers—5 men.

"The saving in crew in connection with an oil-burning installation increases rapidly with an increase in horse-power, i. e., for a 4000 H.P. vessel the crew would be:

Required for coal—12 firemen, 6 coal passers—18 men.

Required for oil—3 firemen, 3 wipers—6 men.

and for a 5500 H.P. vessel:

Required for coal—15 firemen, 9 coal passers—24 men.

Required for oil—6 firemen, 4 wipers—10 men.

"A statement of saving in repairs and maintenance in connection with the use of fuel oil on shipboard in comparison with coal is rather indefinite, inasmuch as there are so many different types of vessels and conditions on which a saving might be based.

"The following is the estimated saving effected on a coastwise vessel of 5000 Gross Tons and 3800 I.H.P. per annum, exclusive of the fuel oil, and covers the following items:

"Wages and subsistence of crew.

Maintenance of vessel's structure in bunkers and fireroom; including painting and renewal of floors, reverse bars, keelsons, tank tops, bulkheads, wooden ceiling, etc.

Grate bars, liners and furnace fittings.

Ash ejectors, ask ejector pipes and pumps and ash hoists.

Fire doors, furnace fronts and ash pans.

Protection plates.

Fireroom floor and supporting angles.

Fire shovels, fire tools and cost of dressing fire tools.

"Estimated saving, $9,000.00.

"All repairs to oil pumps, piping, etc., in connection with the fuel oil installation, have been deducted from the total saving and the above amount is net."

Mr. Charles F. Bailey, Chief Engineer of the Newport News Shipbuilding and Dry Dock Company, to whom I am indebted for invaluable assistance in the preparation of this paper, gives the following figures relative to cost of fitting up vessels to burn oil:

"The cost of fitting up new vessels for fuel oil burning including furnishing and installing furnace fittings, burners, heaters, pumps, piping and oil meters for a 2300 H.P. job, would be about $7000 (weight 40,000 lbs.); for a 4000 H.P. job, about $10,000 (weight 65,000 lbs.). The corresponding value of the coal furnace fittings replaced by oil fuel fittings would amount to about $2000 (weight 44,000 lbs.) and $3500 (weight 75,000 lbs.) respectively. These figures include furnishing and installing the fuel oil burning apparatus in place of coal burning fittings and do not include the oil-tight bunker work, which adds something to the cost of the vessel.

"The cost of fitting a new ship for oil burning is considerably less than converting an old job from coal burning to oil burning, on account of the great amount of structural work which is required to be rebuilt. The cost of the structural work incident to an oil fuel installation on an

old ship depends upon the design of the vessel and length of voyage, so that two ships of the same horse power may differ materially in the cost of conversion. On a vessel of 3800 H.P. a recent estimated cost of conversion amounted to about $70,000, while on another vessel of 2300 H.P. the corresponding estimated cost of conversion was about $25,000''.

The price of oil is of course a fluctuating figure, but it may be of interest to set down the following contract prices taken from the public opening of bids for oil supply for the U. S. Navy. I am told that these prices compare closely with those obtaining in commercial contracts.

Price Fuel Oil Per Barrel (42 Gallons)
Fiscal Years 1914, 1915, 1916.

	Fiscal Year Ending June 30th		
Delivered at	1914	1915	1916
Baltimore, Maryland	$2.08	$1.23	$1.12
Boston, Massachusetts	1.94	1.16	1.06
Charleston, South Carolina	2.09	1.23	1.07
New Orleans, Louisiana	1.69	.98	.84
New York, N. Y.	1.89	1.20	.84
Norfolk, Virginia	2.24	1.23	1.12
Philadelphia, Pennsylvania	1.89	1.20	1.04
Port Arthur, Texas	1.39	.78	.64
San Diego, California	.73	.85	.65
San Francisco, California	.73	.85	.60
San Pedro, California	.65	.80	.60
Seattle, Washington	.83	1.00	.735

While no general statement of cost can be used for obtaining more than an approximation for individual cases, it is hoped that what is given above may be of some assistance in showing the many advantages of oil over coal fuel and the probability of its saving money.

PHYSICAL PROPERTIES OF OIL.

The classification of oils according to their density is very commonly used to denote other characteristics. Thus, a ''heavy'' oil is usually expected to be viscous and sluggish with a high percentage of asphalt and comparatively low heat value, while a ''light'' oil is supposed to be very fluid at ordinary temperatures, very volatile and rich in the lighter hydrocarbons and high in heat value. While in general, these character-

istics hold true enough to explain the prevalent association of ideas, there are so many exceptions and variations that it is essential to clearly specify the various properties of a particular oil in order to identify it. Density is not a measure of volatility, nor does weight necessarily determine viscosity. It may be noted also that the early theory that the density of oil was related to the depth of the oil well, has not been borne out in later exploration.

Analyses of Oil—Heat Value.

Fuel oil depends for its heat value almost entirely upon hydrogen and carbon, which although present in the liquid in many different combinations, still do not vary greatly in relative proportions when reduced to ultimate analysis. Thus, the hydrogen content of various crude oils varies usually from about 11% or 12% to about 14%, and the carbon from about 84% to about 87%, slight amounts of oxygen, nitrogen and sulphur also being present.

The following table is reproduced from Holde's work on Examination of Hydrocarbon Oils:

Ultimate Analyses of Oils.

Source	C	H	O	S	N	Authority
Pennsylvania	86.06	13.89	......	0.06	......	Engler
Oil City, Pa.	85.80	14.04	......	......	......	Mabery
Findley, Ohio	84.57	13.62	0.98	0.72	0.11	Mabery
Lima, Ohio	85.00	13.80	......	0.60	0.68	Rakusin
Beaumont, Texas	85.05	12.30	......	1.75	......	Richardson
Ventura, Cal.	84.00	12.70	1.20	0.40	1.70	U. S. G.
Wasatch Range, Utah	86.86	11.89	0.59	0.64	0.02	Mabery & Byerly
Grossny .906	86.41	13.00	0.40	0.10	0.07	Charitschkoff
Grossny .850	85.95	13.00	0.74	0.14	0.07	Charitschkoff
Tcheleken .8736	86.40	12.44	0.377	......	......	Charitschkoff
Campeni-Parjol	85.29	14.21	......	0.03	......	Edeleanu
Bustenari (Prahowa)	86.30	13.32	......	0.18	......	Tanascu

The ultimate analysis may serve for calculating the heat value of a fuel, but the use of the bomb calorimeter of the Mahler type is universally accepted as standard. In this instrument the latent heat of the vapor formed by the combustion of the hydrogen is included in the result—this proportion

of the heat value is, however, not available for use in a furnace where the vapor passes away as superheated steam.

The heat value of fuel oil varies between about 16,000 and 20,000 B. T. U. per pound, 18,000 to 19,000 being the common values. The following table was prepared from the files of The Babcock & Wilcox Company:

Heat Value—Fuel Oil.

Source	Specific Gravity	B. t. u. Per Pound	Authority
California, Coalinga Field	0.927	17,117	Bashore
" Bakersfield Field	0.992	18,257	Wade
" Kern River Field	0.950	18,845	Bashore
" Los Angeles Field	0.977	18,280	Bashore
" Monte Cristo Field	0.966	18,878	Bashore
" Whittin Field	0.936	18,240	Wade
Texas, Beaumont	0.924	19,060	U. S. Navy
" "	0.903	19,349	Bashore
" Sabine	0.937	18,662	Bashore
Pennsylvania	0.886	19,210	Booth
Mexico	0.921	18,840	Bashore
"	0.981	17,551	Bashore

In a paper published in the Journal of the American Chemical Society, October, 1908, Sherman and Kropff call attention to the apparent relation of the calorific power of petroleum to its density. They present results of calorimeter tests on various oils running from gasolene having a specific gravity of 0.71 with a heat value of 21,120 B. T. U., to California crude oil having a specific gravity of 0.9644 with a heat value of 18,589 B. T. U. per pound, and for these oils they find that the following formula gives results remarkably close to those obtained with the calorimeter:

$$\text{B. T. U. per pound} = 18{,}650 + 40\ (\text{Baumé} - 10).$$

It will be observed that no oils under 15 Baumé were tested, and the accuracy of this formula for such oils, particularly those containing considerable sulphur, is doubtful. It is to be hoped that further experiment along these lines will be made.

Viscosity.

With the advent of the viscous crude oils of Mexico and the increased use of heavy distillates from other fields, coupled

with the wider adoption of the mechanical atomizer, which will be described later in this paper, the degree of viscosity of the oil becomes a matter of considerable importance.

Viscosity may be described as the resistance to internal movement, or the internal friction of a liquid. It may be measured in various ways, as, for instance, observation of the ability of the liquid to oppose the movement of a body through it or immersed in it (Doolittle's disc, for example) or more commonly by noting the time required for a definite quantity of the liquid to pass through an orifice or short pipe under known conditions of temperature and head. This latter principle is used in the best known types of viscometers as developed by Saybolt, Redwood and Engler.

Mr. Geo. M. Saybolt, of the Standard Oil Company of New Jersey, constructed his instrument to meet the needs of his Company in the manufacture, primarily, of lubricants, where the measurement with absolute accuracy of slight differences in viscosity was required in the work of the laboratories of the various factories. This viscometer is well adapted for testing fuel oils, and its accuracy and the ingenious overflow device for bringing the oil to the exact level required after its temperature has been determined, and immediately before the outlet is opened, are among the many features which have led to its extensive use among the oil companies of America. The instrument is now being widely introduced in other fields.

The following particulars apply to the standard Saybolt viscometer, which is illustrated in Fig. 5:

Inside diameter of oil tube	3.0	cm.
Depth, starting level to outlet jet	11.3	cm.
Length of outlet jet	1.3	cm.
Diameter of outlet jet	0.18	cm.
Charging quantity of oil	70	c.c.
Amount of oil discharged	60	c.c.

The time of outflow is taken in seconds by a stop watch, and the viscosity is reported in terms of the number of seconds required for 60 c.c. of the liquid to be discharged. The viscosity of water at 60° F. is 30 on the Saybolt scale.

The oil tube is suspended in a bath of water, or for the

higher temperatures, a suitable oil, and the later instruments are not only provided with the usual gas heating arrangement, but with a steam coil and an electric heater, any of these three methods of heating the bath being used at the option of the operator. The letters on the cut refer to parts, as follows:

A—oil tube thermometer; B—bath thermometer; C—electric heater; D—turntable cover; E—overflow cup; F—turntable handles; G—steam inlet or outlet; H—steam coil; J— oil tube; K—stirring paddles; L—bath vessel; M—electric heater

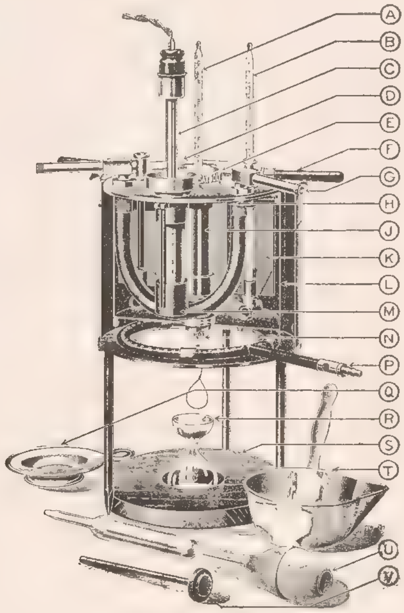

Fig. 5. Saybolt Viscometer (Tagliabue Standard).

receptacle; N—outlet cork stopper; P—gas burner; Q—strainer; R—receiving flask; S—base block; T—straining cup; U—pipette; V—tube cleaning plunger.

Sir Boverton Redwood, whose work on petroleum is world renowned, constructed a small vessel with an outlet "jet" made of agate. The instrument is standardized by use of rape oil, a viscous vegetable product having a specific gravity of 0.915. The agate jet is of such size and the instrument so proportioned that 50 c.c. of the rape oil at 60° F. will flow out in

535 seconds. The oil to be tested is poured into the cup to a certain level and carefully stirred and heated to the temperature at which it is desired to measure the viscosity. Fifty cubic centimeters are then allowed to flow out of the cup and the time is noted in seconds. The viscosity is expressed in terms of the viscosity of rape oil, i. e., as a percentage of the time required for the outflow of the rape oil, and the result is further corrected for the density of the two oils. Fifty cubic centimeters of water at 60° F. will take about 25½ seconds to flow out of the Redwood apparatus. The Redwood viscometer is much used in England.

Dr. C. Engler, of Karlsruhe, uses a cup with a platinum tube at the bottom 20 m.m. in length, with a bore of 2.9 m.m. in diameter at the top, and 2.8 m.m. at the bottom. A volume of 200 c.c. of the oil to be tested is allowed to flow out and the time noted in seconds. The number of seconds required for 200 c.c. of water to flow out at a temperature of 20° C. is then determined (this is 52 to 53 seconds in the standard instrument), and the viscosity of the oil is reported as the ratio of the time required for water to flow out to the time required for the liquid; i. e., the viscosity is found by dividing the time required for the oil by the time required for the water. The viscosity of water is therefore unity on the Engler scale.

The Engler instrument is very widely used on the Continent of Europe, one reason for its popularity being the ease of calibrating with water and the fact that frequent calibrations eliminate errors due to slight wear or inaccuracy of the orifice.

Other types of instruments are also employed and they all include special and important devices for heating and stirring and accurately measuring the temperature of the oil.

Unfortunately the "viscosity" determined by each of these different instruments is on a scale of its own, no two are alike and confusion frequently results from reports which carelessly omit mention of the kind of viscometer used. Furthermore, the size and shape of the orifice and the proportions of the vessel affect the relative rate of flow of the various liquids, so that if rape oil were used by Engler and water by Redwood, two new viscosity scales would be introduced.

I have tried to secure tables giving the comparison of the standard Saybolt, Redwood and Engler viscometers, but while a few comparative figures of this kind are published, as for example, in the United States Navy Oil Specifications and also in Redwood's "Treatise on Petroleum", and elsewhere, I am told that no accurate table can be made for the reason that the relationship of the three scales differs with different characters of oil. This is only one of the added complications of the present practice of measuring viscosity, and in view of the increasing importance of viscosity tests of oil fuel, it seems to be high time for those versed in the art to devise some standard international method for determining viscosity and a standard scale for reporting the results.

One of the methods suggested is that wherein the coefficient of absolute viscosity is found by forcing the liquid at known pressure and temperature through a capillary tube. This was worked out by Poiseuille, whose formula is as follows:

$$AV = \frac{\pi p r^4}{8 v l} t$$

Where $A\ V$ = the absolute viscosity in dynes, or the units required to move a layer of the liquid of one square centimeter area over another layer of the liquid with a velocity of one centimeter per second.

p = pressure in grams per square centimeter.
r = radius of the capillary tube in fractions of centimeters.
l = length of tube in centimeters.
v = volume of liquid passed through the tube in cubic centimeters.
t = time in seconds.

The absolute viscosity of water at 0° C. = 0.018086. If this were taken as unity and the absolute viscosity of other liquids were expressed in these units, the result might be called "specific viscosity". This method is also one which is urged as an international standard. The Engler Scale, while using as a basis the viscosity of water, does not give true "specific viscosity", for the reason that a liquid flowing through an orifice is affected by other things, e. g., the acceleration due to gravity, etc. A method, however, of converting to specific

viscosity the viscosity measured in degrees Engler (using the Engler Standard Instrument), has been worked out by Ubbelohde as follows:

$$S\,V = S\left(4.072\,E - \frac{3.514}{E}\right).$$

Where $S\,V$ = the specific viscosity of the liquid referred to water at 0° C.,

S = the specific gravity of the liquid at the temperature of the test.

E = degrees Engler (Standard Instrument).

With values of Engler degrees greater than 10 (and these are the viscosities which interest us particularly), the fractional part of the formula is comparatively small and may be neglected, and Ubbelohde's formula becomes:

$$S\,V = S\,(4.072\,E).$$

Obviously it would be entirely possible to work out formulae for each of the various fixed types of viscometers. Why then should not "specific viscosity" in the sense used above, be adopted as standard? Would it not be equally as satisfactory as the use of "specific heat" and "specific gravity"?

This subject is treated fully in Holde's work on "Examination of Hydrocarbon Oils"—translated by Mueller, and published by John Wiley & Sons, New York, 1915. Through the courtesy of the publishers, I reproduce herewith a diagram for the graphical determination of specific viscosity when the Engler degrees and specific gravity of the oil are known. Figure 6.

I have discussed this matter at some length, as it seems to me that the growing importance of viscosity in handling fuel oils demands some sort of standard practice and general agreement in place of the present numerous and diverse methods, and the confusion they lead to.

In atomizing oil by means of the mechanical atomizer or pressure burner, it is important to know to what degree the viscosity must be reduced and to what temperature the oil must be heated to accomplish this result. Also, the most viscous oils cannot be pumped without heating. The whole problem,

therefore, of handling heavy oil—in fact any oil—really hinges on the matter of viscosity.

In a valuable paper on oil burning, by Lieutenant-Commander John J. Hyland, U. S. N., published in "The Journal of the American Society of Naval Engineers", May, 1914, the results of some of the experiments conducted by him at the U. S. Fuel Oil Testing Plant at the Philadelphia Navy Yard, are reported. The viscosity of a large number of representa-

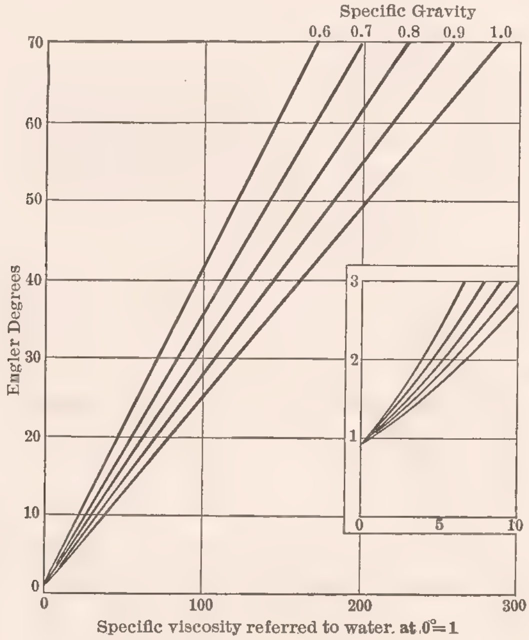

Fig. 6. Curves for Converting Degrees Engler to Specific Viscosity.
(Courtesy John Wiley & Sons.)

tive fuel oils at various temperatures was determined for Commander Hyland by Mr. C. A. Cratty, Chemist at the Yard, and these were plotted by Hyland and published in his paper. I have reproduced the curves on a different scale, omitting, for the sake of clearness, the results at the lower temperatures. In addition to all of Hyland's curves, I have added a few curves for oils used in some of our experiments, the viscosity tests

being made by Mr. E. G. Bashore, Chemist for The Babcock & Wilcox Company.

Commander Hyland found that in order to get full capacity from a 6-in. by 6½-in. by 12-in. Blake pump, the viscosity of the oil had to be reduced to 375° Engler. He states, also, that in order to atomize the oil sufficiently to burn without smoke, using the mechanical atomizer, the viscosity had to be reduced to 8° Engler, and that further heating did not improve the evaporation. In our experiments we have not found it necessary to go quite to the 8° mark, but have found 10° to 12° Engler sufficiently low in viscosity. This is, however, a substantial confirmation of Hyland's figures.

An interesting point in this connection is that apparently the oils naturally the least viscous required reduction of the viscosity to the lower point. Thus, while a light oil required sufficient heating to reduce the viscosity to 8° or 10° Engler, the heavy oils could be handled with equal satisfaction by reducing the viscosity to only 12° or 15° Engler. However, all these heavy oils required heating above 212° F. to get the viscosity down to the 15° mark; and as there was some water present in small amounts in these oils, it is rather tempting to speculate on the effect which might have been produced by the moisture, in flashing into steam at the burner tip.

Flash Point.

The "flash point" of oil is the temperature at which inflammable gas or vapor is given off. It is determined simply by heating the oil and as the temperature rises testing it with a spark or flame until the vapor is distilled off and ignites and the "flash" is noticed. The oil must be carefully stirred in order to get a uniform temperature and measure the same correctly, and it is obvious that conditions of the test may introduce wide differences in results. Thus, merely by closing in the top of the vessel in which the test is made, the "flash" will be detected sooner and at a lower temperature than if the vessel is entirely open. This explains the use of the "closed-cup" as opposed to the "open-cup" apparatus. The former is the more accurate, and instruments devised by Pensky and Marten and by Abel are recognized as standard for fuel oil.

The "burning point" is the temperature at which sufficient vapor is given off to remain ignited, and as a free supply of oxygen is required, this test is made with the open cup.

Heating above Flash Point.

It will be apparent upon inspection of Hyland's curves that certain oils require heating above the flash point—not for any supposed advantage of allowing the oil to flash into gas, but merely for the purpose of reducing the viscosity to a point where the mechanical atomizer will handle the oil successfully. This is undoubtedly a condition which introduces an element of danger in the use of oil on shipboard. Some slight unnoticed leak in the piping system or at a burner may allow gas or vapor to collect in the fireroom, which on being mixed with a certain proportion of air and exposed to a naked light may produce a more or less disastrous explosion.

This element of possible danger is often set aside as of trifling consequence, or not considered at all, or no leak in the piping having occurred, it is contended that none ever will.

Further, it is claimed by some authorities that the vapor which would be liberated in this way is exceedingly small—not enough in fact to introduce any considerable danger. Not being able to learn of any actual tests which had ever been made on viscous crude oil to determine the amount of oil which would be distilled off in the process of heating sufficiently high to reduce the viscosity to 8° Engler, I took the matter up with the U. S. Bureau of Mines at Washington. A sample of Panuco (Mexican) crude from the Bayonne station of The Texas Company was furnished us for the test, through the courtesy of Mr. W. A. Thompson. Unfortunately the results have not been received in time to be presented in this paper.

It must be understood that only a part of the oil is volatilized when a temperature above the flash point is reached; that is, there is no possibility of the whole body of the oil flashing into vapor, but even if a portion is given off, the amount of this vapor may be constantly added to by new oil approaching the hidden leak.

In this connection, the oil specifications of the United States Navy are of special interest—as it will be noted that a "safe" oil is insisted upon.

OIL SPECIFICATIONS—U. S. NAVY.
1915.

(a) Fuel oil shall be a hydrocarbon oil of best quality, free from grit, acid, and of fibrous and other foreign matter likely to clog or injure the burners or valves.

(b) The unit of quantity to be the barrel of 42 gallons of 231 cubic inches at a standard temperature of 60° F. For every variation of temperature of 10° F. from the standard, 0.4 of 1 per cent. shall be added or deducted from the measured or gauged quantity for correction.

(c) Flash point never under 150° F. as a minimum (Abel or Pensky-Marten's closed cup), or 175° F. (Tagliabue open cup), and not lower than the temperature at which the oil has a viscosity of 8° Engler (water = 1 Engler). (Example: If an oil has a viscosity of 8 Engler when heated to 186° F., then 186° is the minimum flash point at which this oil will be accepted.)

(d) Viscosity at 100° F. not greater than 200 Engler.

(e) Water and sediment not over 1 per cent. If in excess of 1 per cent, the excess to be subtracted from the volume; or the oil may be rejected.

Note.—If an Engler viscosimeter is not available, the Saybolt standard universal viscosimeter may be used, and 280 seconds Saybolt will be considered equivalent to 8 Engler, and 7,000 seconds Saybolt will be considered equivalent to 200 Engler. Water at 60° F. = 30 seconds Saybolt.

(f) Water and sediment will be taken by the distillation method. When oil in small lots is consigned to naval vessels or to navy yards, the centrifuge test will be used in order to obviate delay. In this test 50 c.c. of oil and an equal quantity of the best commercial benzol, 50 per cent white, will be used, and the mixture heated to 100° F.

Any oil can, of course, be made "safe" in this respect by distillation, if not by merely "topping" or "blowing" heated air through the oil to drive off the light vapors. Will it pay to do this? Will oil users be content to take the crude oil as they get it, regardless of how much above the flash point it has to be heated? Will the oil companies continue to put this oil on the market? How about insurance? These questions will be answered in the course of time, but at any rate the point ought to be fully understood and the possible danger appreciated by oil users. I wish to take this opportunity to point out that the flash point alone is not enough, but rather the flash point must be considered in connection with viscosity.

Density of Oil—Specific Gravity.

The Baumé hydrometer scale for liquids lighter than water has obtained a strong hold in the oil industry, and for light oils

this practice is justified by the ease with which the "gravity" may be determined—namely, by the simple reading of the scale on the stem of the hydrometer immersed in the liquid. But for heavy viscous oil, the very nature of the oil makes the process a slow one and liable also to considerable error. It is believed by some that for these oils it is much better to determine the weight of a known volume of the oil (as in the specific gravity bottle), and report the density in terms of the density of water at 60° F., i. e., as specific gravity.

On the other hand, there are advocates of the method of heating the viscous oils sufficiently to make the use of the Baumé hydrometer feasible—making the necessary corrections for temperature.

The reluctance to abandon the Baumé scale and give the actual specific gravity is due probably to our inherent dislike to continually report results in fractional units; but as the oils in general use become heavier and the hydrometer itself becomes impracticable, it is probable that the Baumé scale will be less commonly used. In fact, already oils of 10° Baumé (the specific gravity of water) are used as fuel, and should the limit go a bit further, we should be confronted with the alternative either of reporting the density in terms of specific gravity, or of bringing into use the other Baumé scale, for liquids heavier than water—a most undesirable complication.

The United States Bureau of Standards has adopted the following formula for converting readings on the Baumé scale lighter than water, to terms of specific gravity:

$$\text{Specific gravity at } 60^\circ \text{ F.} = \frac{140}{130 + \text{Baumé}}$$

I am informed that many Baumé hydrometers on the market are constructed with scales on the modulus of

$$\text{S. G.} = \frac{141.5}{131.5 + \text{Baumé}}.$$

For fuel oils, the difference is negligible; but of course if specific gravity is to be figured from the reading of a hydrometer, the formula should fit the instrument.

The following table is given for reference:

Temperature-Viscosity Diagram of Fuel Oils

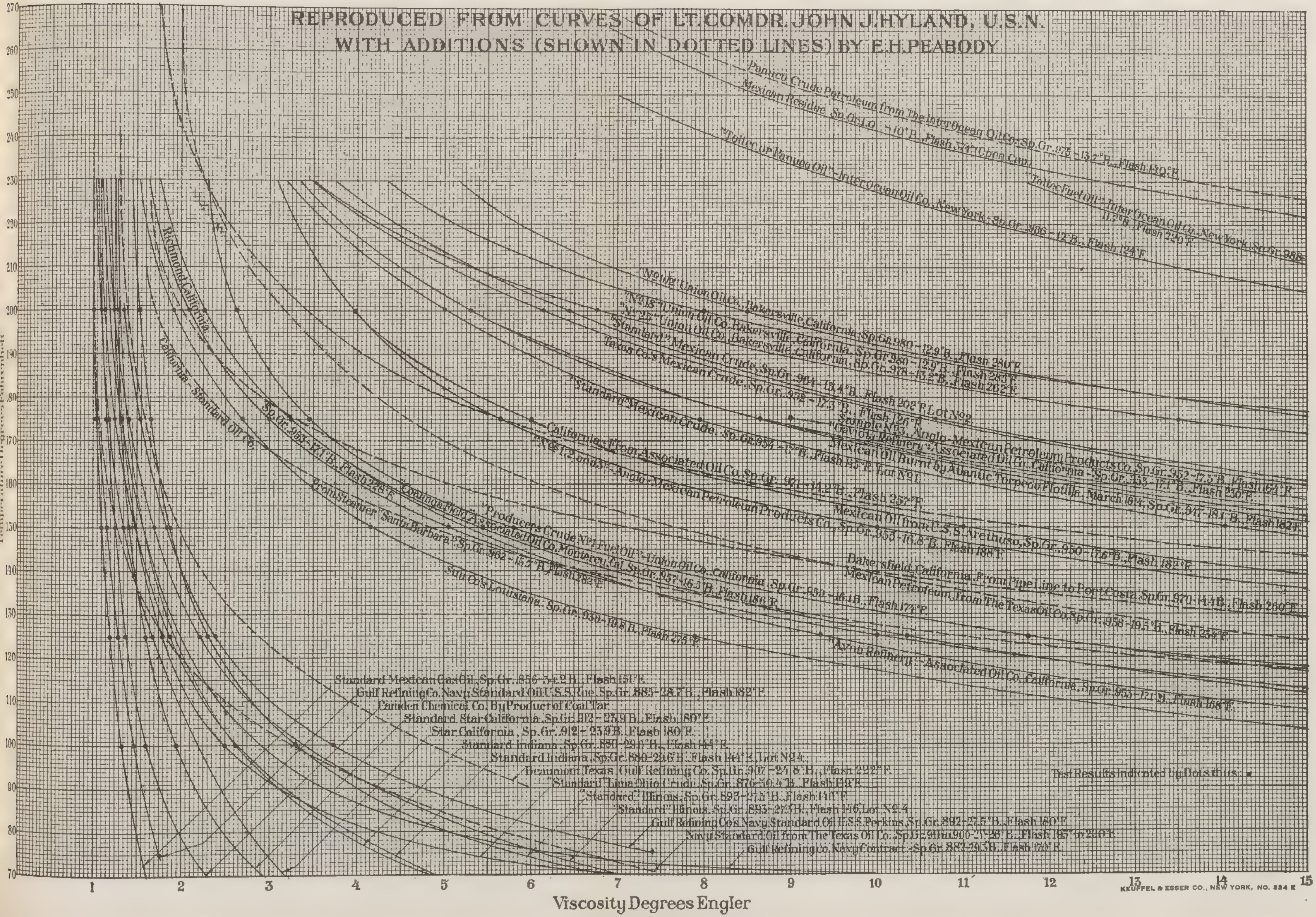

Fig. 7. Temperature-Viscosity Diagram.

Baumé Liquids Lighter Than Water	Specific Gravity 60° F.	Weight in Pounds—60° F. Per U. S. Gal.	Per Cu. Ft.	Per Barrel 42 Gals.
10	1.000	8.337	62.368	350.2
11	0.993	8.280	61.93	347.7
12	0.986	8.222	61.50	345.3
13	0.980	8.171	61.12	343.2
14	0.973	8.112	60.68	340.7
15	0.966	8.054	60.25	338.3
16	0.959	7.996	59.81	335.8
17	0.952	7.937	59.37	333.4
18	0.946	7.887	59.00	331.3
19	0.940	7.837	58.63	329.2
20	0.933	7.779	58.19	326.7
21	0.927	7.729	57.82	324.6
22	0.921	7.679	57.44	322.5
23	0.915	7.629	57.07	320.4
24	0.909	7.579	56.69	318.3
25	0.903	7.529	56.32	316.2
26	0.897	7.479	55.94	314.1
27	0.892	7.437	55.63	312.4
28	0.886	7.387	55.26	310.3
29	0.881	7.345	54.95	308.5
30	0.875	7.295	54.57	306.4
35	0.848	7.070	52.89	296.9
40	0.823	6.862	51.33	288.2

Specific Heat of Oil.

The specific heat of oil varies with its composition. It will be greater the richer the oil is in hydrogen, and lower in proportion to a greater carbon content.

The following figures are reproduced from Holde's work on Examination of Hydrocarbon Oils, referred to above:

Crude Oils From—	S. G.	S. H.
Japan	.862	.453
Pennsylvania	.810	.500
Russia	.908	.435
California	.960	.398
Bustenari	.842	.462

Coefficient of Expansion of Oil.

It may be considered that at ordinary temperature crude petroleum expands under the influence of heat approximately five ten-thousandths (0.0005) of its volume for each degree

Fahrenheit (0.0009 per degree C.). This coefficient decreases for the heavier oils being a function of the specific gravity.*

CONVERSION OF VESSELS FOR USE WITH COAL OR OIL.

While the U. S. Navy has definitely adopted oil fuel for all classes of service and the later vessels are constructed without provision for coal bunkers, it may appear of advantage to the mercantile vessel owner to be ready to use either fuel. This can be easily accomplished if means are provided for carrying coal fuel.

The change of the boilers consists merely of removal of the burners and oil piping, air-controlling mechanism and special brickwork that may have been used, and substitution of a few necessaries, such as grate bars and fire doors. In fact, where steam atomizing burners are used, the grate bars and bearers are usually retained while burning oil, and merely covered with a protecting layer of fire brick.

The changes in the bunkers also are simple, if proper precautions are taken beforehand.

Mr. George Simpson, the well known naval architect, gives the following rules for arranging the bunkers for alternate use with either fuel:

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* Subsequent to the presentation of this paper, a valuable treatise reporting the investigations of the Bureau of Mines on the coefficient of expansion of California crude oils and distillates was presented at the first annual meeting of the American Petroleum Society at San Francisco by Mr. A. S. Crossfield. The conclusions arrived at are as follows:

"1. The value of the coefficient now used in California practice approximates 0.0009 per 1° C. (0.0005 per 1° F.). From the results of this investigation it is apparent that this value is considerably too high, and that the correct value more nearly approaches 0.00072 per 1° C. (0.0004 per 1° F.).

"2. The value of the coefficient for crude oils and distillates, within the ranges of temperature used, is a straight-line function of the temperature and increases with an increase in temperature.

"3. The value of the coefficient for crude oils, within the ranges of specific gravity used, is a straight-line function of the specific gravity and decreases with an increase in specific gravity. The value for distillates deviates somewhat from a straight line."

SPECIFICATION FOR COAL OR FUEL-OIL BUNKER.

General Description.

"The cross bunker to be arranged adjacent to the fireroom and to consist of two thwartship oiltight bulkheads of a predetermined capacity. There shall be a centreline oiltight bulkhead dividing the cross bunker into port and starboard compartments, and in addition there shall be partial swash bulkheads extending throughout the upper half of the bunker.

"The hatchway shall consist of a coaming 24" in height plated over the top and arranged with two oil hatches.

Oiltight Bulkheads.

"The oiltight bulkheads must be suitably stiffened with vertical stiffeners and webs, as well as horizontal girders, the scantlings and arrangement being as required by Lloyd's Rules for oiltight work. The centreline bulkhead should extend from inner bottom to coaling hatch with plating and stiffeners to Lloyd's requirements.

Hatchway.

"A steel cover on top of the 24" coaming forming the hatchway shall be arranged with hinges and drop bolts to enable the whole of cover to be readily opened up for coaling purposes, and when carrying oil this cover will be arranged with a lamp wick gasket and the cover screwed down and made oiltight. In addition there shall be two small oil hatches on the main hatchway cover arranged so as to be readily opened and fitted with peep holes and ventilators.

Coal Doors.

"The stokehold bulkhead to be arranged with coal doors of the usual dimensions, the frames of which shall be secured with bolts and nuts so as to be readily removable when changing over to oil, and a steel plate cover substituted and set up on a lamp wick gasket, or alternatively, the plate may be riveted in place and caulked.

Fuel Oil System.

"The fuel oil system shall consist of a high and a low suction in each tank led to Warren or other suitable oil fuel pumps with the usual arrangement of heaters, duplex strainers, meters and thermometers, the whole system being cross-connected and interchangeable so that the breakdown of one pump need not put that particular unit of the system out of commission, but can be connected up with the other pump and these pumps so cross-connected that each can handle its own or opposite system.

Finally.

"Generally there is no practical difficulty in arranging a cross bunker for the stowage of either coal or fuel oil provided the hatchway is made large enough and arranged with a steel cover. Care should be observed in arranging the wing swash plates that they shall only extend for the upper part, thus permitting the coal to gravitate freely to the bunker doors.

"With a system such as has been outlined in the foregoing, a change over from one fuel to the other can be made in a few hours."

PRECAUTIONS AGAINST DANGER.

The time is long past when the use of oil fuel on shipboard is opposed on account of insurmountable danger. Oil has the distinct advantage over coal that it is not subject to spontaneous combustion, and many fires which have occurred in ships' bunkers at sea would not have been possible with oil. Certain precautions, however, must be taken—such as suitable arrangements of vent pipes, protection of bunker bulkheads, if exposed to heat, and particularly the use of an oil with a reasonably high flash point. The United States Navy, in co-operation with the Bureau of Mines, has investigated the matter of possible explosion of gases in storage tanks, and it was found that no inflammable gases were formed in any amount in the storage tanks or bunkers until the oil was heated to the flash point, i. e., that the representative oils tested contained no dissolved gas or vapor sufficient to form an explosive mixture at temperatures below the flash point. The largest percentage of vapor in the atmosphere of fuel oil tanks of various battleships tested was 0.04%, whereas, about 0.9% is required to form an explosive mixture. It was also found that any oil in the bunker tank had to be heated to within 60° F. of the flash point before even a faint "glow" or partial burning was obtained on introducing a naked flame in the tank.

These important investigations show that oil is perfectly safe on board ship so long as the flash point is sufficiently above the temperature to which the oil may be exposed.

On the other hand, while careful attention to ventilation of the tanks and leading the vent pipes well away from all possible chance of exposure to flame may result in immunity from trouble, the conclusion is forced upon us that the use of heavy oils which have to be heated in the tanks and bunkers may lead to very serious consequences through the necessity of installing heating coils in the tanks, and the possibility that the oil may become heated to the flash point through carelessness. This is a different matter entirely from heating the oil for use at the burners. The oil may be pumped at temperatures

which are perfectly safe—but what assurance is there that it may not be overheated by careless handling of the heating coils in the tanks. It seems to me that this matter has been relegated to the condition where safety against explosion depends too nearly on vigilance alone. The steam smothering pipes which are usually installed provide fairly effective means for extinguishing possible fires in the tanks, and the U. S. Board of Supervising Inspectors of Steam Vessels recommend that valves should be fitted on all suction pipes on the inside of the tank, with stems extending to the deck above the tank; they also recommend similar extensions to the valve rod on the steam connection to the oil pump, so that the latter may be shut down from outside the fireroom. The only other precautions are the fitting of lead pans underneath Scotch boilers to catch any drip of oil due to leakage, and the provision of a supply of sand in the boiler room itself for the purpose of extinguishing incipient fires. These precautions may prevent fires but not explosions. Automatic devices for closing the valves on the steam-heating coils in the tank when the oil reaches a predetermined temperature might be advisable, but even then "eternal vigilance is the price of safety".

I have already referred to the possible danger due to heating oil above the flash point, and there is always the potential danger that some careless or ignorant fireman may try to light a burner which has been atomizing oil and injecting it in the form of spray into the furnace for some time previous to lighting. In this case it is quite possible that an explosion in the boiler furnace may occur, and for this reason, some engineers object to having dampers installed in the uptakes, or if installed, they insist on having them locked in the open position. This by the way will not prevent an explosion under the above conditions. Personally, I am a strong advocate of the use of the damper for air regulation and I believe that the added danger due to having the damper closed is of little account. If the simple precaution is taken of always having a lighted torch under the burner before turning on the oil, no possible danger of explosion in the furnace can exist.

Several methods of extinguishing fires at sea by the use of carbonic acid gas are being developed, such as the Gron-

wald System, advanced by the British Ships Fire Syndicate of Cardiff, Wales, which consists of the installation of tanks at suitable points containing liquid carbonic acid gas under high pressure. These tanks are piped to various parts of the ship, where possible danger from fire might exist, and the gas is admitted to these points in emergency, thus, completely blanketing the fire and shutting off the supply of oxygen.

Another system which has been very effective in extinguishing fires in oil tanks ashore is that known as the Erwin System, manufactured by Treadwell and Company of New York. A mixture of bicarbonate of soda and soap bark is carried in one tank, and sulphuric acid is carried in another, nearby, and these may be mixed automatically or at will, resulting in the liberation of a large mass of foam impregnated with carbonic acid gas.

Carbon tetrachloride has been used for extinguishing fires; this is best known in commercial form in the portable tanks of Pyrene.

It occurs to the layman that quite as much danger may result from the installation of tanks of this highly asphyxiating material on board ship as would be caused by fire, but undoubtedly experience will show the efficiency as well as the necessity of these various methods of extinguishing fires.

STORAGE ON BOARD.

By no means the least of the advantages of oil over coal is its adaptability for storage in almost any part of the vessel—in the ordinary bunker space, or in tanks remote from the fireroom, or in double bottoms. Special precautions must be taken to prevent and to detect leakage from the tanks. Special riveting is employed and frequently coffer-dams are built around the oil tanks. Coffer-dams around the oil tanks are recommended but not insisted upon by any of the Classification Societies, except where "low flash point" oils are allowed, i. e., oils having a flash point below 150° F. In other words, while oil is easily handled, the feasibility of its use on shipboard depends primarily on the ability to keep it where it is stowed until it is pumped to the burners. In deep tanks, swash plates are installed to prevent undue motion of the liquid in the tanks when partly filled. Expansion trunks are provided to allow for

increase in volume due to heating; vent pipes are carried above the decks to carry away vapor given off by the oil. These are fitted with goose-necks at the top covered with wire gauze, and sometimes in destroyers or vessels of low freeboard the vents have special automatic valves at the end instead of the simple goose-neck, for discharging vapor and at the same time preventing water from entering the tanks.

Sounding pipes for measuring depth of oil in the tanks are provided. These should be of ample size, anything less than 2½ in. being unreliable for deep tanks in which viscous Mexican oil is carried. It is advisable to drill small holes in these pipes to give free access to the oil at all depths, as it is possible for some difference in density to exist at the various levels, if the oil has been standing for some time. Heavier oil at the bottom would give an erroneous reading if the sounding pipe were open at the bottom end only.

In closed tanks the combined area of the vents and sounding pipes must be sufficient to provide an adequate overflow in the case of too rapid filling, which might put an undue pressure on the tank. For this reason, when tanks in the lower part of the vessel, such as the double bottoms, are used for oil, it is advisable to fill through a system of relay tanks which eliminates the danger of a large "head" of oil exerting a heavy pressure on the storage tanks. Mr. Bailey has furnished me a diagram of the system being installed on the Battleships "Pennsylvania" and "Mississippi," which is here reproduced with the permission of the Navy Department. See Figure 8.

Two 6-in. pipes with valves are located on each side of the ship, connecting with one 8-in. filling pipe on each side, which runs to the relay tank. The latter is fitted with a removable cover and a large (10-in.) overflow closed by a relief valve with a very light spring. Filling pipes lead from the relay tank to the storage tanks, and it is evident that the greatest pressure which can be put on the latter is that due to the head from the relay tank, which can be reduced to a small amount by suitably locating such tank. The vent pipes from the storage tanks lead into the relay tank, which is fitted with a common vent pipe leading to the atmosphere and covered at the end with wire gauze. The supply pipes to the relay tanks

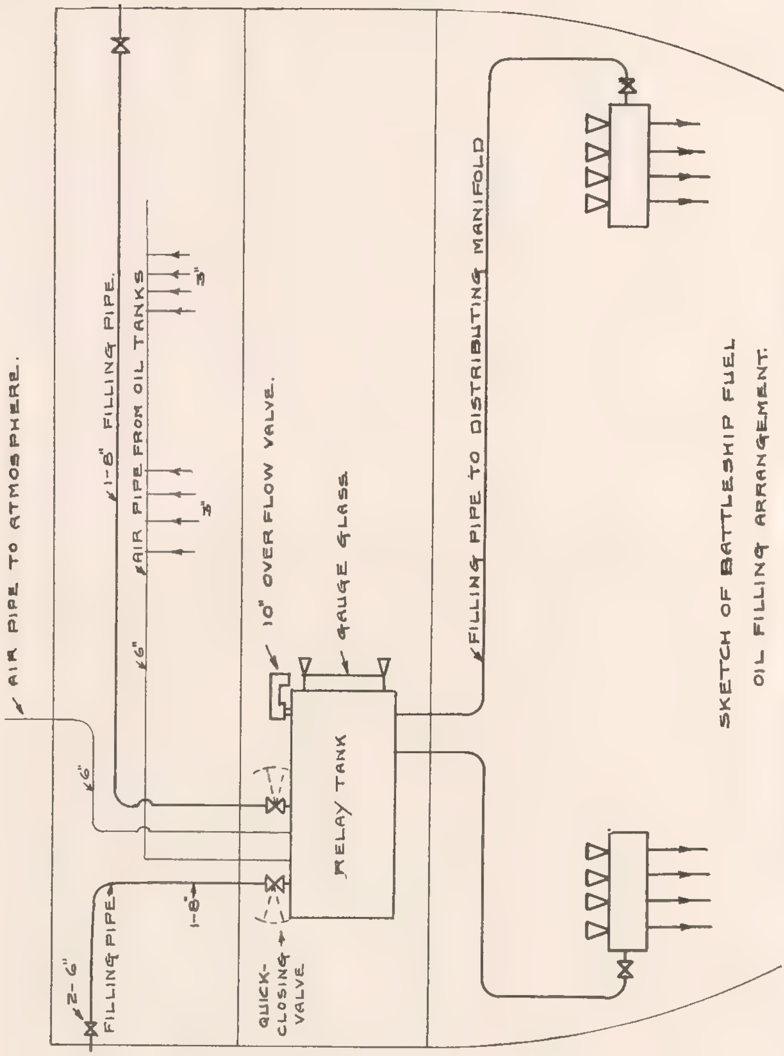


Fig. 8. Filling Pipes and Relay Tanks, U. S. S. "Pennsylvania".

are fitted with quick-closing valves and the relay tank is equipped with a gage glass to mark the level of the oil. Also an annunciator at the relay tank, operating from the "pneumercators" fitted in the storage tanks, gives warning when the latter are 95% full. On the relay tank which is used only in filling and not for permanent storage, the fitting of a gage glass is no doubt justified, but the use of fittings of any kind on the outside of the tanks below the oil level is in general very bad practice, and should be avoided where possible. Notwithstanding reports of trouble due to loss of vacuum, I question even if pump suctions could not be fitted through the top of the tank, thus avoiding all possible danger of oil leaking, or breaking loose in case of accident.

Floating suctions, in storage tanks, for taking the oil from a point near the surface are no longer considered necessary, the usual practice being to use a high and low suction, i. e., two pipes either separate or connected through a manifold, one taking the oil from a level 12 or 18 inches from the bottom of the tank and the other from a point within a few inches of it—not more than four inches. The upper suction is used for regular service, and at all times except in emergency—or when the supply is very low or when the low suction is employed to pump overboard water or very dirty oil which has accumulated at the very bottom of the tank.

Several very serviceable and inexpensive oil installations have been made by Captain Charles A. McAllister, Engineer-in-Chief of the United States Coast Guard, by setting up cylindrical oil tanks either in the coal bunkers or elsewhere for oil storage. This method is well adapted for small vessels.

OIL MEASUREMENT.

For the calculation of evaporative results, fuel used for power, heat value, etc., units of weight are employed, i. e., the pound, kilo, etc. (1 kilo = 2.204 pounds avoirdupoise); but for measurement of bunkers, cargo tanks and in general sales contracts, the oil is figured by volume; thus, in the United States, the usual units are the U. S. gallon (231 cubic inches = 3.785 litres) and the barrel of 42 gallons. The litre and the Imperial

gallon (4.54 litres) are used abroad, where the barrel is figured at 41 Imperial gallons (50 U. S. gallons). The Imperial gallon equals about 1.2 U. S. gallons. I understand that some of our oil companies favor the Imperial barrel (50 U. S. gallons) as a matter of convenience, but 42 gallons is the accepted standard.

For statistical purposes, the ton (2240 pounds) and the "metric ton" or 1,000 kilos (2204 pounds) are frequently used.

Volumetric measurement of oil should always be based on a standard temperature, the usual figure in this country being 62° F. The Navy Department specifies 60° F, and a correction of 0.4 of 1% is made for each 10 degrees variation from this standard.

Oil meters have been frequently installed in the pipe lines to burners, and as a check on consumption they are of value. All meters, however, are liable to error—and it is not always the same error; besides it may easily happen that the piping arrangement is such as to allow the meter to register while circulating the oil through the system preparatory to lighting up, thus vitiating whatever approach to accuracy the meter might possess.

Tank measurement is in the long run most reliable if properly safeguarded. Valuable data on this subject may be found in an article by Howard C. Towle in "International Marine Engineering" for August, 1912.

Lieutenant-Commander Walter B. Tardy, U. S. N., Engineer Officer of the U. S. Battleship "New York" makes the following statement concerning an apparatus called a "pneumercator", which seems to offer a very accurate means for tank measurement. I understand that this instrument is being applied not only on shipboard, but for shore storage stations as well—and for any sort of liquid measurement in tanks:

"The accurate measuring of fuel oil in tanks that are either being filled, or from which oil is being used, is accomplished by means of the Pneumercator, see description by Mr. H. B. Gregory in the "Journal of the American Society of Naval Engineers", May 1915.

"This instrument provides at all times an absolute check against invoices or withdrawals from the tank, as well as shows the amount of oil available at any time.

"To accomplish this no floats or diaphragms are necessary in the tanks,—the instrument working by air pressure, compressed by the head of the oil in the tank.

"The Mercury Registering Gauge can be instantly reset to prove the accuracy of the reading indicated. In case a high or low alarm is desired, no electrical connection is necessary to the tank,—the connection being between the Mercury Gauge and the Annunciator. This is a most important feature as it does away with all danger of short circuits and consequent sparking in the vicinity of the fuel oil.

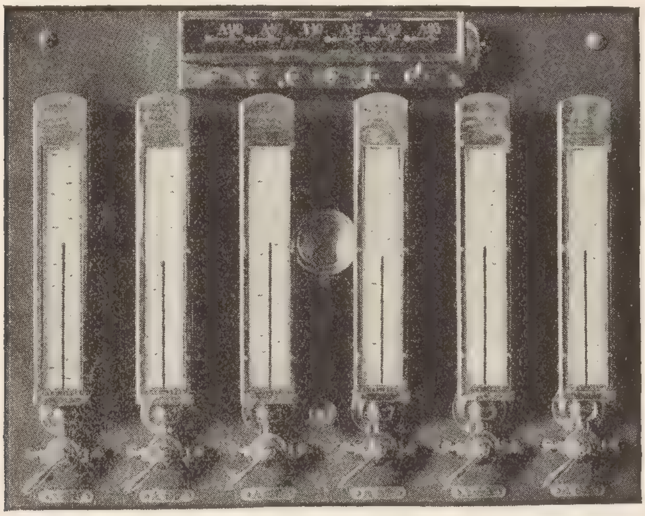


Fig. 9. Pneumercator.
(Four units like the above complete the set for the U. S. S. "Arizona".)

"The Pneumercator has been adopted by the United States Navy to measure the fuel oil in ship's storage and relay tanks, and is now installed, or about to be installed in all the oil battleships.

"The illustration (Figure 9), shows the recording equipment, complete with annunciators for low alarm, on one of the latest United States battleships (Arizona). The gauge boards are located at the booster pumps, one gauge being connected to each tank.

"The accuracy of the Pneumercator readings is best illustrated by the following service incident: On the 'New York', the hourly consumption of Peabody burners was determined by the Pneumercator on several occasions. On the acceptance trial of this vessel the fuel oil burned was accurately measured in tanks on deck, under the charge of the Official Trial Board. This measured hourly burner consumption differed by less than 0.1 gallon from that established by Pneumercator readings."

SETTLING TANKS.

If the oil put aboard a vessel contains water in material amount, which by nature of the oil can be separated out by settling, or if water gets into this grade of oil in the storage tanks on board ship, the duplicate system of settling tanks, considered an essential part of all early systems, is a valuable means of preventing trouble in the fireroom—the oil being allowed to stand some hours in one tank while the fuel-oil supply is taken from the other.

The oil companies are now, however, delivering oil for fuel purposes practically free from water; and with care, water may be kept out of the oil after it has been put aboard the vessel. It is true that the very heavy viscous oils which are much used for fuel contain considerable moisture, but this cannot be removed from the oil in a great degree by any practical means of settling, even when the oil is heated. Besides this, it is an interesting fact that the water bound up in these heavy oils causes little or no trouble in the burners, owing doubtless to its finely divided condition and even distribution throughout the oil.

It would seem, therefore, that settling tanks are a rather useless incumbrance and that the oil can be taken directly from the storage tanks to the burners, the high suction being used ordinarily and the low suction providing means for pumping overboard any water which in the course of time settles in these tanks. The depth of the tank and its location also have a decided bearing on this point, deep tanks resulting in more of the separating process than comparatively shallow compartments, such as double bottoms.

While there is some difference of opinion on the subject, the U. S. Navy Department has dispensed with settling tanks in all classes of oil-burning craft in the service, and uses only a booster pump for lifting the oil to the suction of the service pumps. The booster pump is of course no assistance in separating the water from the oil.

CORROSION DUE TO OIL.

Certain grades of the heavier oils contain considerable sulphur and the question is frequently asked whether or not cor-

rosion from this cause may result. At the opening of the Beaumont fields, particularly, there were many, who on general principle, prophesied rapid deterioration of boiler surfaces, without giving due thought to the fact that certain kinds of coal having a larger sulphur content than the oil had for years been used for fuel without serious trouble. Experience has demonstrated that sulphur in oil has no bad effect on boilers, except in cases of neglect, when pitting may occur under certain conditions, the same as with coal.

Corrosion of copper heating coils has, however, been noticed in the presence of sulphur-bearing oils, and for this reason it is the recognized practice to use steel coils. Brass and bronze fittings may be used, however, with safety, both in pumps and on pipe lines, and doubtless brass heater tubes could be employed if desired.

OIL PUMPS.

Mr. W. A. Ebsen of the International Steam Pump Company has at my request kindly made the following comments on oil pumps:

"The pumps designed, and usually preferred, for handling crude or fuel oils are of the duplex piston pattern, except for large capacities accompanied by heavy pressure, where an outside-packed plunger pump is to be recommended.

"With the piston pump there is only one small stuffing box for the piston rod, so that the opportunity for leakage, with its resulting danger of fire, is reduced to a minimum. With an outside-packed plunger pump, there is more or less drip or leakage from the large stuffing boxes.

"The handling of high-gravity fuel oils, running from 30 deg. Baumé up, and quite liquid in consistency, is usually best accomplished by the use of an ordinary duplex pump fitted with brass ring packing in the pump pistons and brass valves and special oil-proof gaskets in the pump cylinder joints to overcome the solvent action of the oil. For heavy viscous oil, like Mexican crude, the ordinary duplex piston pump is suitable, provided a size sufficiently large is selected to keep down the oil velocities through the ports and passages and valve seats in the pump cylinders to a minimum. For ideal conditions, the velocity through the valve seats should not exceed a speed of 100 ft. per minute for pumps of large capacity, and about half of this for small pumps. For light oils around 40° Baumé the above velocities can be doubled.

"The type of pump ordinarily used for pumping fuel oil to burners, where the oil pressure will not exceed 150 pounds per square inch, is a pump similar to the Snow Duplex piston-pattern pump. In selecting this

type for low-gravity oils, it is advisable to use nothing smaller than a 4½" x 2¾" x 4" size, as the ports and valve passages in small pumps are too restricted to operate successfully with oils of this character, and it might be well to remember that the 4", 5" and 6" stroke duplex fuel-oil pumps have valve areas equivalent to 35% to 40% of the piston area and should operate at speeds, say, not to exceed 30 to 40 single strokes per minute each piston, and 10" and 12" stroke pumps 25 to 30 single strokes. For example, take the 6" x 4" x 6" size operating at 30 strokes—

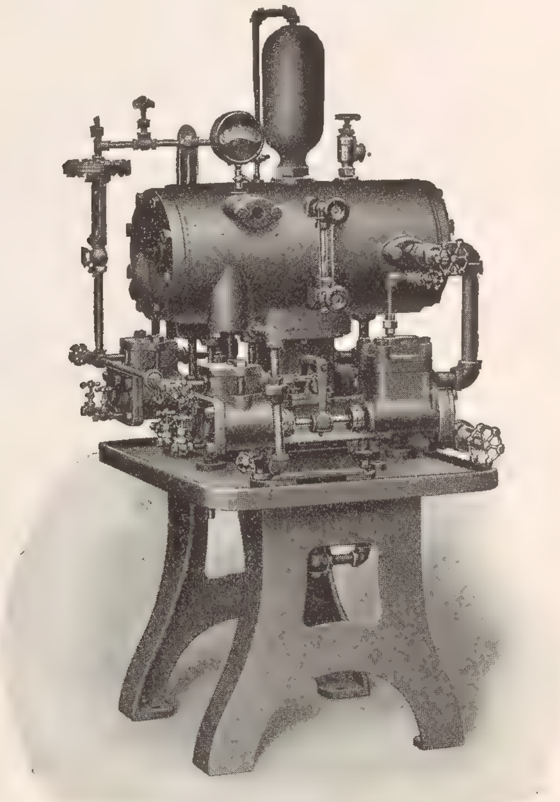


Fig. 10. Fuel Oil Pumping Outfit.
(International Steam Pump Co.)

this would represent a piston speed of 15 ft. per minute, and the resulting speed of the oil through the valves will be about 40 ft. per minute, which is well within the limit.

"These pumps are very often set in duplicate on a cast iron stand with an oil heater, strainers, by-pass valves, thermometers, gages, etc., and are shown as Fuel Oil Pumping Systems. See Figure 10.

"With this arrangement one pump is operative and the other is a reserve. A pressure governor or regulator is set for the oil pressure and controls the pump automatically. These systems are usually used in connection with low-pressure burners of the steam or air atomizing type. In rare instances, the single-cylinder pump is used, although in this country the duplex pump is favored.

"For high-pressure fuel-oil systems it is necessary to use pumps designed for operating against oil pressures up to 200 pounds per square inch. For horizontal work, the duplex-pattern pump of the valve-plate style makes a very efficient and satisfactory pump for the service. For Naval installations or for marine work where floor space is limited, the vertical duplex Admiralty pump attached to the bulkhead is usually employed. This type of pump is good for 300 pounds maximum oil pressure.

"The same remarks made above with reference to the selection of the size and capacity of the pump, apply to the high pressure pumps.

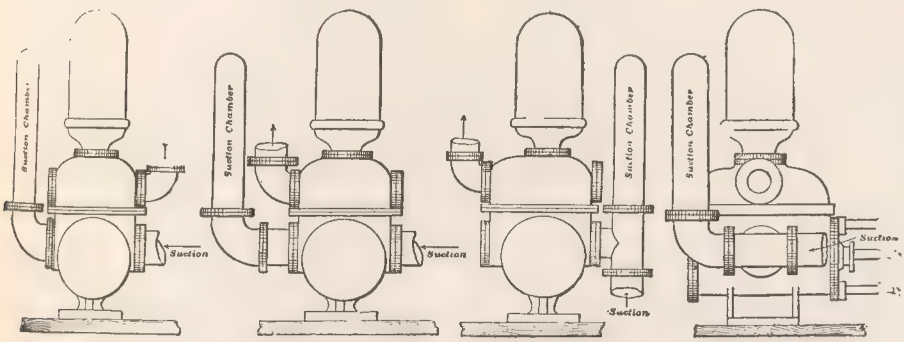


Fig. 11. Suction Air Chambers.

"The duplex fuel-oil pump has been universally regarded as the standard in the United States, while in England, for Admiralty purposes, they occasionally use vertical simplex pumps, which, if properly fitted up with suction air chamber and discharge air chamber, will give almost as steady and constant a flow of oil as the duplex pump.

"The simplex pump, both of the horizontal and vertical type, has better suction qualities than the duplex. The former are usually made longer stroke and permit the use of half the number of valves, which necessarily have to be of larger diameter than in the duplex pumps, and consequently are more favorable for the flow of heavy, viscous oils. On board ship where the bottom of the fuel oil tanks is placed below the location of the pump, the simplex pump, with its better suction qualities, will drain the tank in a more satisfactory manner than a duplex pump. A suction air chamber should be so arranged as to permit the direction of flow through the suction pipe to cushion against the air or gas con-

tained in the suction chamber, rather than have the flow pass directly into the suction opening of the pump. See Figure 11.

"The pump valve service ordinarily used in fuel-oil pumps is the plain bronze disc valve spring loaded, or with a wing-guided bronze valve; the latter is used in the Snow heavy-pressure pattern and in the Blake vertical duplex Admiralty pump.

"For large-capacity crude-oil pumps we have adopted double- and quadruple-beat valves, which pumps have only one valve per section, the valves being of large diameter, with a very low lift. A valve of this type will give full passageway through the valve discs, as would be ordinarily the case with a disc valve, thus necessitating high lift; the oil will pass out through annular openings in the seat and have practically four outlets through the valve. This type of valve reduces slip to a minimum, reduces the wear and is practically noiseless.

"With reference to the manner of fitting fuel-oil pumps, there is some diversity of opinion, but the ordinary construction for stationary service is to install pumps fitted with bronze-lined pump cylinders, iron pump pistons, fitted with spring ring packing and steel piston rods. For marine service it is usual to install brass-fitted pumps, that is, arranged with bronze pump pistons and bronze piston rods. For handling crude oils containing considerable sulphur, steel piston rods and hard cast iron pump cylinder linings give better service, especially if the oils contain considerable grit. A fibrous-packed pump piston is not to be recommended, as there will be danger of clogging the burners with shreds of packing passing out with the oil."

The "fuel-oil pumping outfit" described above by Mr. Ebsen is a very convenient, compact arrangement for use with steam atomizers, and similar outfits are made by numerous burner manufacturers and others. It is likely to be modified to meet the high pressure and temperature requirements of the mechanical atomizer, in which case duplicate heaters of large capacity are essential. An arrangement of this kind designed by Mr. W. A. White of the Washington Engine Works, is shown in Figure 12.

While the reciprocating pump has been very largely used for pumping oil to burners, there are several makes of rotating plunger pumps which give very satisfactory results for this purpose, and have the advantage of giving a very much steadier oil pressure. These pumps utilize the well-known principle of the rotary engine, and experimental tests at League Island have shown them well qualified for use with mechanical-atomizing oil-burning installations.

Air Chambers.

A steady oil pressure at the burners is of prime importance and this can only be secured by the installation of adequate air chambers to neutralize the pulsation of the pumps. The whole thing about the air chamber is to make it tight against air leak-

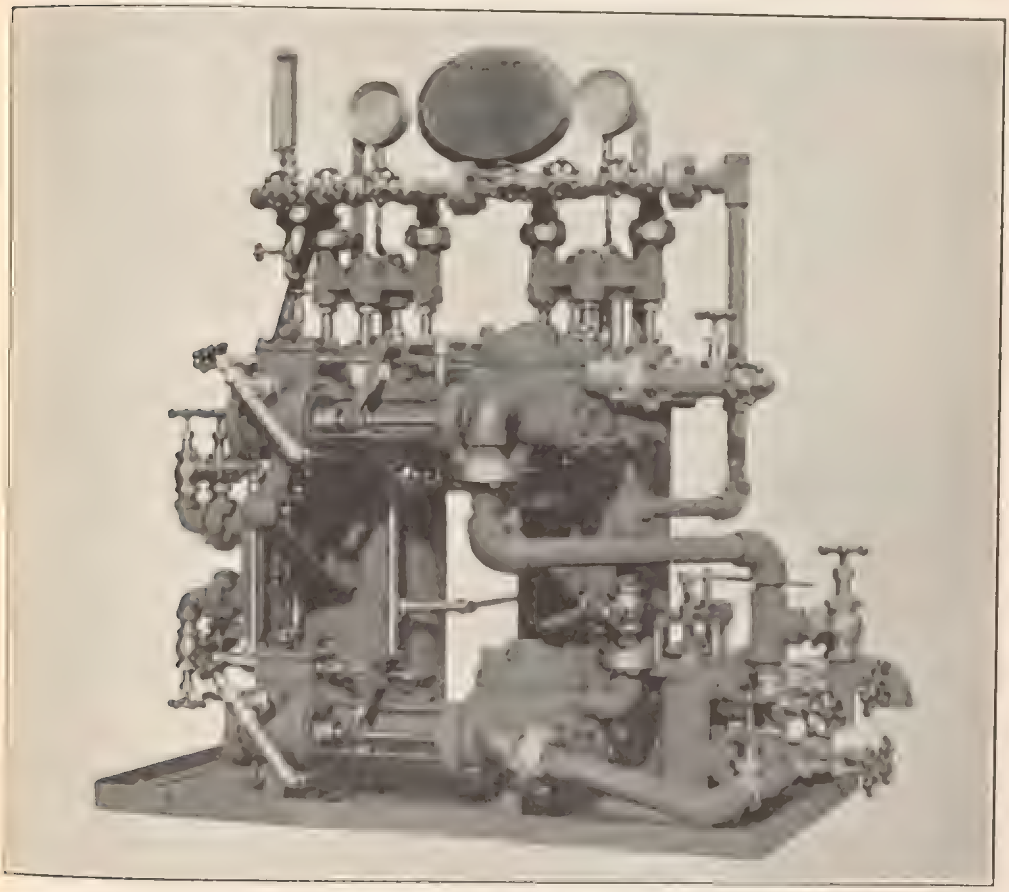


Fig. 12. White Oil Fuel Heating and Pumping Outfit for Mechanical Atomizers.

age, have it big enough and provide ample and direct means for the oil pressure to act on the air. Very minute leaks will gradually dissipate the air and destroy the effectiveness of the air cushion. Any sort of connection above the oil level is likely to be a source of leakage; but, on the other hand, the efficiency of the air chamber is greatly increased by charging with com-

pressed air so that connections to the top of the chamber are not infrequent, although there seems to be no good reason why the compressed air could not be admitted below the oil level and pass up through it to the air chamber.

It has been claimed that the rapid depletion of air in the air chambers is due to absorption of the oxygen by heated oil. I am disposed to attribute this, however, to minute air leaks in the air chamber.

PIPING.

For U. S. Naval service the oil piping specified is seamless drawn steel, with flanges expanded on. The joints are scraped and made up metal to metal. Manila paper gaskets are allowed on suction piping. Screwed fittings are used on connections under ¾-in.

For merchant service extra-heavy welded-iron or steel pipe is used, with screwed joints and with extra-heavy galvanized-iron fittings. Flanges are screwed on the pipe and manila paper or card board is used for gaskets, or special oil-proof packing, of which there are several kinds in the market. Rubber is not allowable on account of sulphur in the oil. Copper piping is not used on account of the sulphur, but brass and composition fittings, valves, unions, etc., may be used safely.

The suction piping should be large, the Newport News rule for designed velocity of Mexican oil through suction pipes being not over twenty feet per minute, the oil being heated to reduce the viscosity to about 300° Engler. For discharge pipe lines they consider 100 feet per minute allowable in small pipes, the viscosity being reduced to 15° Engler or under.

Mr. Bailey states that—

"As we pipe from the service pumps to the oil burners we reduce the speed of the flow near the end of the lines, i. e., we do not reduce the piping in proportion to the oil used, as we find it necessary to reduce the flow in order to maintain the pressure at the burners on the end of the line farthest from the service pumps. With Navy fuel oil, and where we do not make allowance for changing to heavy oil like Mexican oil, we allow about double the speed in the discharge pipe to the burners that is allowed with Mexican oil. For instance, in the 'Pennsylvania', the service-pump discharge to the heaters is proportioned for about 130 feet velocity per minute, the discharge from heaters to burners is proportioned for about 230 feet per minute in 2½-in. and 2-in. pipes, respect-

ively. As the lines reduce we have in 1½-in. pipe 185 feet, in 1¼-in. pipe 195 feet, and in ⅜-in. pipe, to each burner, 128 feet velocities per minute. Our Destroyer practice in regard to piping and oil speeds is substantially the same as that for the 'Pennsylvania'.''

For valves on suction lines designed for viscous oils, the gate valve is preferable, on account of reduced friction. On delivery lines, globe valves of a regrinding type give satisfaction. There is no occasion to use needle valves. Where fine regulation is required, as in some cases with steam atomizers, there are several types of valves which open gradually on slotted or ''V'' shaped passages which give better and more consistent results than the needle type. All valves for high pressure work should be extra heavy with bonnets screwed over, not into, the valve body. Specially designed and packed plug cocks may be used in small sizes for quick action.

Through the courtesy of the Bureau of Steam Engineering, I am permitted to reproduce plans of the oil piping of the U. S. Torpedo Boat Destroyer ''Patterson'' (see Figures 13 and 14), together with the following description and notes referring to battleship practice, by Mr. H. B. Gregory of the Bureau. This description summarizes many of the points mentioned above.

Oil Equipment—U. S. S. ''Patterson''.

''The system comprises storage tanks forward and aft, and two settling tanks in each fireroom, abreast of the boilers, together with the necessary pumps, oil heaters, strainers, etc.

''In each fireroom there are one light service supply pump, two duplex pressure pumps and two oil heaters, each of sufficient size to heat all the oil used in same compartment to the desired temperature. For raising steam with no source of power available, a hand pump is provided in each fireroom, of suitable size to supply oil at necessary pressure to two burners.

''From the bottom of each forward storage tank a pipe is led to the suction and filling manifold in the forward fireroom. A similar manifold is provided in the engine room connected to pipes from the after group of storage tanks. From each manifold a combined suction and discharge pipe is led to the combined suction and discharge manifold at each supply pump. There are Macomb strainers in both suction and discharge connections between the manifolds and the pumps.

''The supply pumps normally draw from the storage tanks and discharge into the settling tanks, which are cross-connected in each fireroom for maintaining the same oil level in both tanks. In order to prevent overflowing the settling tanks, the starboard tank in each fireroom

is fitted with a float, which actuates a chronometer valve in the steam line to the supply pump, automatically shutting it down when the oil in the tank has reached a predetermined height. The supply pumps are also arranged for transferring oil from the forward to the after storage tanks and vice versa. They are also fitted to draw from the settling tanks and to discharge overboard when cleaning tanks. These pumps can also discharge oil to another vessel in emergency, via the deck filling connections. All tanks are filled from the deck via supply pumps, combined suction and discharge pipes.

"Extending from just below the mid-depth of each settling tank, with end surrounded by a steam coil, a suction pipe is led to the service pumps, in same compartment and fitted with strainers, at pumps. The service pumps discharge through strainers and heaters, the latter arranged with by-pass to the oil burners. Large air chambers are provided on the pumps' discharge. The cutout valves to the burner lines, across boiler fronts, are fitted for emergency operation from the deck above.

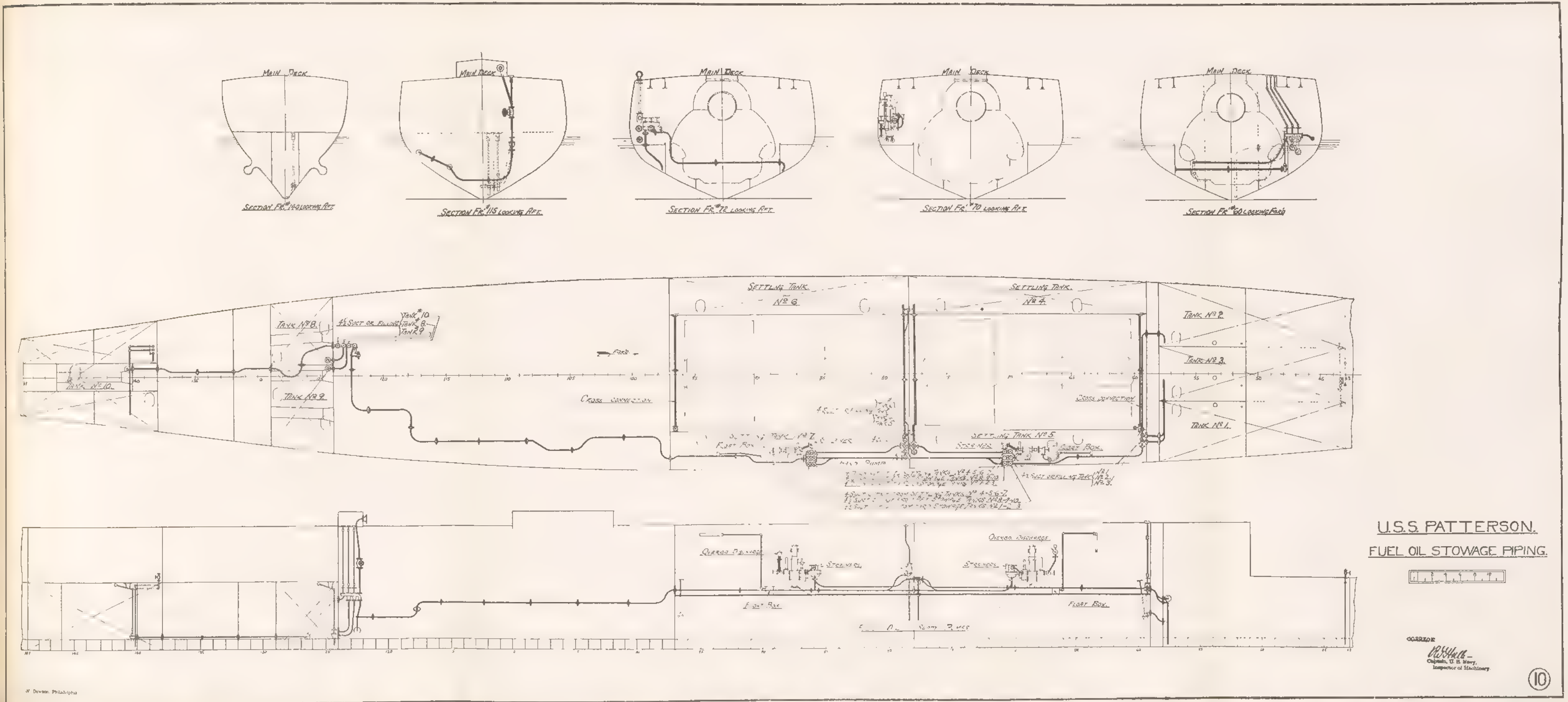
"A hand pump is also provided in the after fireroom for freeing the settling tanks of water and discharging same overboard.

"Notes—In the latest destroyer practice the settling tanks have been omitted and the supply pumps are replaced by booster pumps, which perform, in general, all functions previously done by the supply pumps, except that a discharge connection to the service pump suctions replaces the omitted discharge to settling tank. In some cases the service pumps can also draw direct from the storage tanks in addition to the booster pumps discharge. High and low suctions were fitted in a few cases in storage tanks, but these have since been abandoned. The ends of all suction pipes in storage tanks are now surrounded by steam coils to facilitate handling of oil. Since the omission of settling tanks, each storage tank is provided with a drain pipe about 1¼" diameter, led from lowest point in tanks to a manifold which connects to the booster pumps' suction, thus permitting water and sediment being pumped overboard by the booster pumps. The float control for supply pumps is not generally fitted.

Battleships.

"The practice on battleships is similar to that for destroyers, except as noted below.

"Each storage tank is provided with a high and a low suction, the former, extending to within about 12" of the bottom of the tank, is the normal suction, and the latter, extending within about 2" of the tank bottom, is used only when cleaning tanks or in emergency with low oil in tank. The high and low suctions are often led in two independent mains from the tanks to manifolds, but it is preferable to combine the two, external to the tanks, into a common main to reduce the piping to a minimum. This is easily accomplished by providing two valve manifolds at the tank tops or fitting internal double-suction valves operated from the tank tops.



F[illegible] 17. Oil P[illegible], U.S.S. "Patterson."

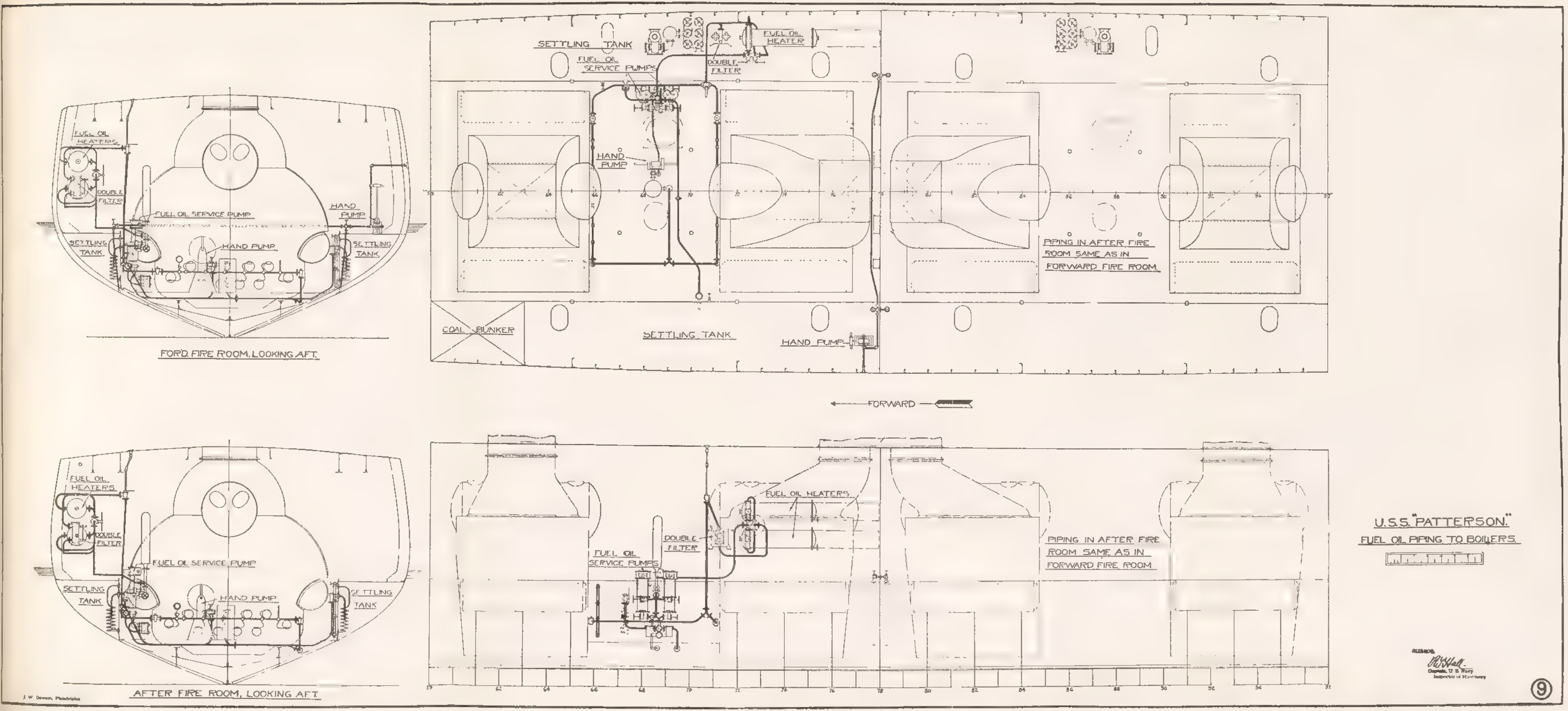


Fig. 14. Oil Piping, U. S. S. "Patterson".

"The booster pumps on battleships discharge into a main forming a continuous loop common to all firerooms, from which the service pumps take their suctions.

"Settling tanks are not fitted on battleships.

"As the height of the deck filling connections above tanks on battleships is sufficient to produce excessive head on the tanks when filling, relay tanks are interposed between decks into which the filling connections discharge, the relay tanks in turn draining by gravity to the filling manifolds below. In this way the maximum possible head is reduced within safe limits.

"Emergency filling connections are also provided at the vessel's side leading direct to booster pumps' suctions, the pumps discharging the oil to the tanks, relief valves the full size of pump discharge being provided to prevent excess pressure on the tanks.

"Hand pumps for draining storage tanks are not fitted on battleships, this service being performed by the booster pumps through the low suctions."

STRAINERS.

The comparatively small orifice of the mechanical sprayer necessitates special care being taken in straining the oil. Most makes of burners are fitted with individual strainers, that used in the Peabody burner being shown in Figure 15. The spool is wrapped with three turns of brass netting of 40-to-the-inch mesh, fastened with No. 20 gauge brass wire. This is easily renewable when necessary.

Strainers of the McComb type are also used both on the pump section and delivery lines. See Figure 16. These are fitted in duplicate, so that alternate cleaning is possible without allowing the oil ever to pass unfiltered. There is little variation in design of filters but considerable difference in practice as to size of mesh, which varies from one-quarter inch to one-sixteenth inch on the suction strainers and from one-sixteenth inch to one hundred mesh to the inch in the discharge strainers, the latter being rather too fine and fragile for good practice. Mr. Bailey recommends pressure gages on each side of the strainers, so that undue fouling will be indicated by the difference in pressure. There is some question as to whether strainers are needed on both suction and delivery oil lines. This will depend greatly on the oil—but the viscous oils hold tenaciously every foreign substance that gets into them, and straining facilities should rather be increased than diminished. At

all events, the oil delivered to mechanical spray burners must be as clean as practicable to prevent clogging, and to minimize wear of the orifices.

HEATERS.

Viscous oils, particularly when used with mechanical atomizers, have widened the field and increased the importance of oil heaters. Where formerly a single small heater, operated with

Fig. 15. Strainer Used with Peabody Burner.

the exhaust steam from the oil service pumps, was found adequate for the lighter oils and steam or air atomizers, it is now necessary, in order to use, or be prepared to use, the heavy oils on the market with mechanical spray burners, to install heating

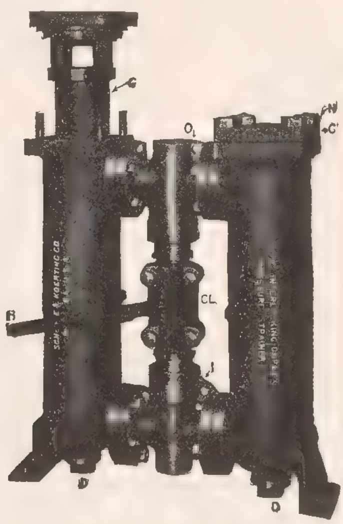


Fig. 16. Oil Strainer.
(Schutte & Koerting Co.)

coils around the pump suction in the storage tanks, and to have in or near the fireroom, heaters using live steam and sufficient in capacity to heat the oil to perhaps 270° or 280° F. With

mechanical atomizing burners, the heater is quite as important as the pump, as with viscous oil the plant is inoperative without it. Duplicate heaters are therefore necessary, one for regular operation and one for spare; or for large plants, what is perhaps better "commercial engineering" and quite as effective, it is quite common to install three heaters, two being used together in regular operation, and one spare.

Of the main oil heaters, Mr. Bailey says:

"Most of our merchant arrangements show three oil heaters fitted with steel coils. In some cases we have piped these with the steam in the coils, but we now pipe most of our jobs with the oil in the coils. In all of our heaters we fit a small relief valve to the oil connection; this is necessary to relieve the pressure due to expansion of the oil in case steam should be turned on when the oil valves are closed. The drains for the steam condensed in the heaters (including the bunker heaters) are led to an inspection tank, those from the pressure heaters are trapped to the tank."

These inspection tanks are for the purpose of detecting any possible leakage of oil from the coils which might ultimately get into the boiler-feed water, and Mr. Bailey further recommends placing a small test cock in the drains for the same purpose. All heaters should also have outside joints on the oil connections to minimize the danger of leakage of oil into the feed-water system through heater drains.

Mr. J. F. Metten, Chief Engineer of the William Cramp & Sons Ship & Engine Building Company, says in regard to design of heaters:

"We use the formulae for heat transmission given in the tables, which of course vary with the velocity of flow through the heating tubes. Where we can, we use four-pass heaters, making the first and second passes of larger area than the third and fourth, on account of the change in viscosity as the temperature rises. We use seamless steel tubing on account of its increased strength and because this material will permit of better expanded joints being made than is possible with softer metal such as copper."

The film heater invented by Mr. L. D. Lovekin and manufactured by the Schutte & Koerting Company is a most ingenious design, and tests have shown it to be the most effective heater yet devised. The oil is forced in a thin film between two steam-heated surfaces of such shape that the oil is continually

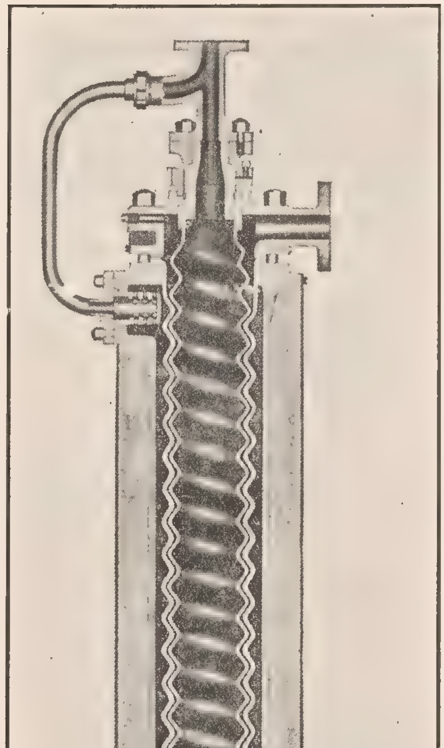


Fig. 17. Film Oil Heater.
(Schutte & Koerting Co.)

being mixed or stirred in passing through the heater. The construction will be apparent from the illustration, Figure 17. The remarkable results obtained with this type of heater used for heating feed water are described in an article in the "Journal of the American Society of Naval Engineers" for May, 1915, by Professor Leo Loeb. Mr. Lovekin's work has upset the old rules relative to heat transmission.

Most of the shipbuilding companies that install oil-burning apparatus make oil heaters, one of which is illustrated in Figure 18, showing the Union Iron Works design.

It will be evident, from what has already been stated regarding viscosity, that heaters are necessary in the storage tanks and bunkers to permit of the oil being pumped to the main heaters, where its viscosity is reduced sufficiently for atomizing. The tank heaters consist usually of coils of iron pipe about 1½-in. diameter located near or around the pump suction. These coils must be able to heat the oil as it enters the suction sufficiently to reduce the viscosity to about 375° Engler, or lower.

In the case of fuel tanks or bunkers, it would not seem necessary to heat the oil throughout the entire tank, and thus in the case of the double bottom attempt to "warm up the whole ocean", providing local heating in the immediate vicinity of the pump suction could be carried out rapidly and uniformly enough to heat the oil as it was pumped away. In this case the size and heating surface in the heating coil should be proportioned to the rate at which the oil is pumped out of the tank rather than to the size of the tank. The situation relative to cargo tanks is different, owing to the high rate of speed at which the oil is handled by the cargo pumps.

Prevailing opinion seems to be opposed to carrying very viscous oil in the double bottoms, on account of the very large heaters necessary; and the usual practice also is in favor of heating the oil throughout the entire tank previous to starting the pumps. Thus, in the cargo tanks of oil-carrying vessels, flat coils are often installed near the bottom of the tanks in addition to the coils around the suction, the combined heating surface of the two sets of coils being figured at the rate of 1/10 of a square foot of heating surface per barrel of oil of the total capacity of the tank. About 40% of this surface is allotted to

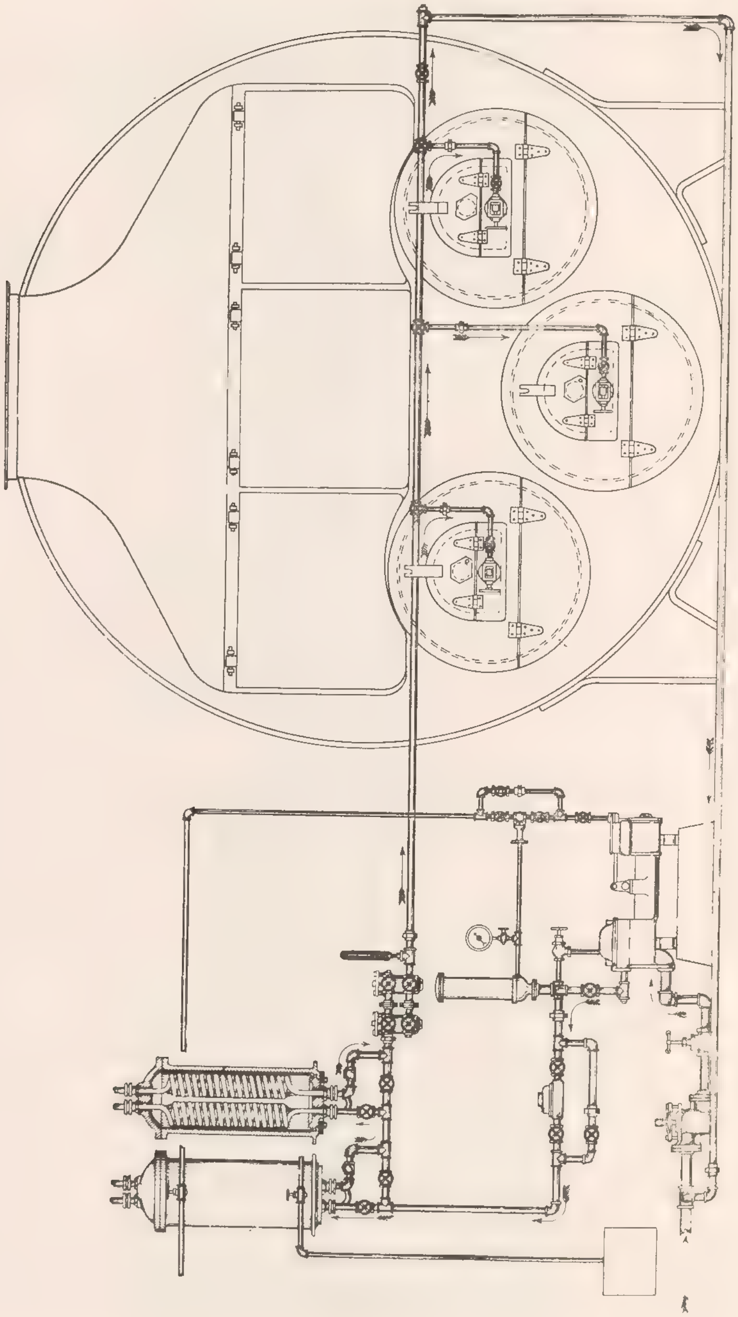


Fig. 18. Oil Heaters. (Union Iron Works Co.)

the suction coils and 60% to the flat coils. The Southern Pacific Company's practice is to put Mexican oil on board at 110° F. and maintain about that temperature during the voyage rather than heating up the cargo when discharging. The economy of this policy depends of course on the length of the voyage.

OIL FUEL FOR GALLEY PURPOSES.

The small consumption this involves hardly warrants mention here, but evidence is accumulating that satisfactory methods for cooking and heating with oil are being developed. Published circulars of the various devices on the market seem to avoid detailed description of the apparatus and to enlarge on workmanship, material and "years of experience" of the inventors. However, the field is promising and worthy of investigation by owners of ships using oil fuel.

EARLY METHODS OF BURNING OIL.

An authentic history of the first developments in methods of burning liquid fuel is much to be desired and I had hoped to include a brief reference to it in this paper. I am indebted to Mr. George F. Gourley of the U. S. Patent Office for much valuable assistance in looking up this subject and he has called my attention to an English patent granted to Alexander Cruikshank, in 1839 (eleven years before Young's patent), for a method of producing "liquid tar" from coal, and including "certain new and advantageous arrangements for applying to useful purposes the heat and light to be obtained from such tar and from oils, etc." Cruikshank shows how the "heat attainable from liquid fuel may be applied to the generation of steam," his method being to inject the oil, by means of a "syringe" worked by an engine, into the furnace, on and among a lot of hollow clay balls, which being brought to an incandescent heat, aided in the combustion of the fuel.

On June 27, 1865, an English patent was taken out by Brooman as a communication from Schpakofsky and Stange of St. Petersburg, which shows a small apparatus for blowing a blast of air at right angles across the end of an oil pipe. Apparently these people had no thought of applying the device

to boilers, but they claim broadly "burning liquid hydrocarbons in the state of spray formed by and mixed with a blast of air".

Six years before this (in 1859) Warner and Tooth took out an English patent for forcing liquid hydrocarbon into the tuyére of a blast furnace. They considered the air only as a supporter of combustion and did not mention any spraying effect, but the combination undoubtedly acted as an effective atomizer.

Following the Russians a few months (Oct. 16, 1865), an English patent was granted to Wise, Field and Aydon. This Field was the famous "tube within a tube" boiler inventor, and Aydon afterwards did considerable work with oil fuel. These three inventors claimed eleven inventions in this one patent—including improvements in boilers, novel methods of evaporating water with superheated steam, water purifiers, step grates and down-draft furnaces, and eighth on the list, and not given exceeding prominence, notwithstanding its apparent novelty and importance, a method of using petroleum by injecting it by means of superheated steam into the furnace. They describe several atomizers, and then follows this significant statement—"other forms of injector may be used for injecting the petroleum if preferred".

Certain authors have given credit for the epoch-making invention of the oil sprayer to Wise, Field and Aydon, or their contemporaries, Schpakofsky and Stange, but the above reference to "other forms of injector" seems to me to indicate that some earlier experimenter deserves this honor, possibly Warner and Tooth, or the American, Hill, who in 1863 took out a patent in which he claimed "the employment or use of a mixture of hydrocarbon liquid with steam as fuel in furnaces."

It is most interesting to note, also, in passing, that an American patent was granted to one Frederic Cook, in January 1868, for an apparatus which sprayed oil by mechanical means and for which the following claim is made: "the introduction and distribution by centrifugal force of liquid hydrocarbon into furnaces as fuel, etc." Cook forced the oil into one end of the spindle or shaft of a device which was rapidly revolved by power, the oil being thrown off radially as a spray from the other end of the shaft which was fitted with a suitable disc or cone.

This idea was revived in 1902 by Harvey D. Williams, one of the Technical Secretaries of the U. S. Liquid Fuel Board, but did not get out of the experimental stage. I have just learned, however, that "rotary burners" working on this principle, operated by electric motors, are in successful use on the Pacific Coast for house heating and cooking.

Undoubtedly the earlier attempts to burn oil were along the lines of surface combustion from pans, stepped or inclined troughs or plates, or by wicks or absorption by porous substances, and also by various methods for heating and vaporizing the oil exterior to the furnace, and burning the vapor.

The open pan method is still successfully used in small furnaces for heating and drying where the combustion is of limited capacity and at a more or less uniform rate. This form of apparatus has been applied to boiler furnaces, as for example, in the device patented by Ludwig Nobel, in Russia in 1883. Experience has shown, however, that except for very small powers it is not a practical method of using oil fuel for steam purposes. This was again proved only a few years ago by a test conducted at the Boston Navy Yard, where a very successful metallurgical furnace designed by Oakleigh was applied experimentally, but without satisfactory results, to a stationary boiler.

There have been many advocates of the vaporizing principle, i. e., the conversion of the oil to vapor or gas before admitting to the furnace. Patents involving this idea have been issued in great numbers, but the only one to attract attention for boiler work of late years is that granted to F. Koerting (U. S. 1905), covering the process in which the oil is heated considerably above the normal flash point, but retained in liquid form and the vapor prevented from distilling off by maintaining the oil under pressure. It is then conveyed to the burner and injected into the furnace, where the pressure is suddenly released and a portion of the oil is converted into vapor by the heat stored in it—the rest being atomized in the usual way. This process patent was at first thought to have covered the entire field of mechanical atomizing and attracted much attention until it was found that the viscosity of the oil

was the controlling feature, and heating the oil was of value only as a means of reducing the viscosity.

Over forty years ago, Commodore Isherwood summed up the situation relative to oil burning for steam purposes by stating that atomization or spraying "is the only method that has been attended with success". This holds good to-day.

ATOMIZERS: STEAM, AIR, MECHANICAL.

It is also true that the three methods referred to above in the early patents are still employed in boiler work—i. e., spraying by means of steam and compressed air and the mechanical application of centrifugal force. In the latter case, however, the simpler method of utilizing the oil pressure for giving the liquid a rapid whirling motion inside the burner tip has practically displaced the rotating spindle and plate.

Other methods for the production of an oil spray by mechanical means are referred to in the English patent to Norton and Hawkesley, 1867. They describe methods of forcing the oil between two surfaces pressed tightly together by a spring, or allowing two small jets of oil to impinge on each other at high velocity, or allowing a single jet to impinge on a plate or other obstacle. My own experiments with these methods have been quite unsatisfactory and probably any success which Norton and Hawkesley might have had was due to the use of an air blast admitted with a whirling motion around the atomizer.

I have been informed that recently promising experiments have been made with mechanical sprays produced by forcing highly heated oil under pressure through small orifices or narrow slots without giving the oil any rotary movement and therefore without the application of centrifugal force. The successful mechanical atomizer, as we know it today, however, depends on the principle of giving to the oil a rapid whirling motion in a chamber in the tip and liberating it suddenly from a small orifice concentric with the axis of rotation. The centrifugal force engendered sprays the oil in the form of a hollow cone, the minute particles of oil flying off radially. The spray itself has no rotating movement unless this is brought about by a whirling body of air admitted around the burner tip.

The flat-spray mechanical atomizer has as yet attained no commercial prominence, though it seems to have possibilities and certain advantages, particularly for low draft conditions, and in furnaces of low head room. It is possible to flatten the flame from a round spray burner by special regulation of the air for combustion—the Babcock & Wilcox application of this idea being used in several U. S. battleships.

Burners which spray the oil by centrifugal force by giving the liquid a whirling motion inside the tip are so closely allied to similar devices for spraying water that doubtless some sort of link exists. Just who is to be credited with the first application of this principle to oil burning, I do not know, although published statements seem to agree that the Koerting Brothers abroad were among the pioneers in introducing the mechanical spray—particularly on shipboard.

It is to the British Admiralty, however, that we owe the modern development of the mechanical atomizer. In the few years following the discovery of Spindle-top, they applied this type of burner to water-tube boilers operating under forced draft at high capacity, and thus attracted attention to its larger possibilities for marine service. In 1907 the United States Navy followed the example of England and really introduced the mechanical atomizer in America, and with the increasing production of oil, its use has been rapidly applied to the merchant marine and it is today recognized in its many varieties as the standard type for extended sea service—though for harbor use or where fresh water is easily obtained, the steam atomizer has a deserved standing which it will not easily surrender.

As an atomizer, *per se*, nothing that I know of can exceed the effectiveness of the steam atomizing oil burner. I have many times looked into a boiler furnace operating with this type of burner and been able to see every brick and joint of fire clay all glowing with incandescence, not a vestige of flame being present. Such a condition of flameless combustion may be obtained with air as an atomizing medium, but cannot, so far as I know, be obtained with mechanical atomizers. Owing to the high expenditure of steam, it does not pay to regularly operate under these conditions; but I am speaking of the effectiveness of the various types as sprayers.

But in economy of fuel, also, for steam production the steam atomizer is second to none. A widely circulated statement, by a high authority on oil burning, makes it appear that there is a difference in economy of fuel between the steam and the air atomizer of 12% in favor of the latter—though it is claimed that this is reduced to 4% by deducting the cost of compressing the air. I find it hard to accept this first statement as a fact. It may be quite possible, as stated by Mr. E. G. Spilsbury in his discussion of Mr. W. N. Best's paper in the Proceedings of the American Institute of Mining Engineers, 1914, that steam atomizing oil burners are objectionable in steel furnaces owing to the liability of hydrogen from the dissociated steam being absorbed by the metal, thus making it brittle; but for boiler purposes there is no objection to steam atomizers, and cheapness and simplicity have resulted long ago in their general adoption on shore. In my experiments with stationary boilers of the Babcock & Wilcox design in California, in 1902, I repeatedly obtained boiler efficiencies exceeding 82%, with steam consumption by the burners less than 2½% of the output of the boiler, giving, after deducting the steam used by the burners, nearly 80½% net efficiency. Doctor D. S. Jacobus obtained nearly 81½% net efficiency with steam atomizers at Redondo in 1908. I question if it is possible to exceed these figures one iota by the use of air atomizers. There is certainly no such gain as 12%, or even 4%. I think there is a general misapprehension in regard to steam atomizers and that this is due to calculations based on tests made under adverse conditions and to academic considerations based on the fact that air supports combustion and steam does not.*

* Since this was written, the writer has had some interesting correspondence with Mr. William N. Best in whose book, "The Science of Burning Liquid Fuel", the statement referred to appeared. Mr. Best has applied his burner to many styles of furnaces for heating, etc., in various industries, and uses the term "furnace" to indicate this sort of installation as distinguished from boilers. His conclusion that compressed air was more economical than steam was based on tests of two rolling mill furnaces of similar size and construction, one equipped with air atomizers, and one equipped with steam atomizers, both operating at 80 pounds pressure. Mr. Best points out also the objection of using steam for atomizing in furnaces

The steam atomizer is further frequently compared, to its disadvantage, with the mechanical atomizer—it being contended that as the latter uses no steam directly for atomizing, whatever percentage of the fuel expense is represented in operating the steam atomizer goes into the coffers of the purchaser who may replace the steam sprayer with a mechanical atomizer. Admitting, for the sake of argument, that the steam consumed by the steam atomizer exceeds somewhat the extra cost of operating the pumps at the higher pressure and heating the oil to the higher temperature required by the mechanical atomizer (I know of no reliable tests to determine this point), I think that the answer is found in the fact that no authentic tests on record, using mechanical atomizers, show boiler efficiencies as high as those obtained with steam atomizers; in fact, the steam atomizer holds the record for economy.

It is claimed further, by some, that the oil atomized per burner per hour by a mechanical atomizer is greater in amount than that atomized by a steam or air atomizer. In general, the reverse is true—but this is rather a question not of burner, which can be made any size, but of air admission, which rather favors the steam or air burner. It is true that as at present ordinarily installed, with the air for combustion admitted underneath the broad flat flame of the usual type of steam atomizer, the number of burners which can be used with a boiler of given size is considerably less than the number of mechanical atomizers which can be installed. In the latter type, the air for combustion is admitted around the burner through the boiler front. By using a large number of burners therefore, the mechanical atomizer is capable of giving very high boiler capacity with forced draft—higher than the steam atomizer as at present installed, though I believe the possibilities of this latter type in the matter of ultimate boiler capacity have not

remote from the boilers. While the paragraph in Mr. Best's book limits the statement of relative efficiency of steam and air atomizers to "furnaces" (meaning other than boiler furnaces), quoted references fail to emphasize this distinction which is very naturally explained by the fact that the term "furnace" is applied quite as freely to boiler installations as to those of other types and, it will be admitted, with entire propriety. It is to be regretted that a meaning has been attached to Mr. Best's figures which he did not sanction nor intend.

been fully developed. Outside of Naval work, where very high forcing is required, the steam atomizer fills every requirement as to boiler capacity.

The real advantage of the mechanical atomizer lies in its simplicity as compared with the air atomizer and its saving of fresh water as compared to steam atomizers. The latter are cheaper to install and fully as simple to operate, and in some respects they surpass the mechanical type. For harbor service therefore, they will long find a field of valuable service in marine work.

In speaking of air atomizers, it should be noted that there is little or no difference between the types using air at 30 pounds and over, and steam atomizers; in fact, the two styles are practically identical. The low-pressure air burners (air at a few ounces) are of different design and in a class by themselves. A representative burner of this kind is that known as the Lassoe-Lovekin Burner, and it was installed on many of the earlier ships, with much success, by Mr. Lovekin.

Steam atomizers of every conceivable design have been evolved and are used extensively on shore and for harbor work. The round-flame type is best adapted to the Scotch boiler furnace, though on account of its usual superiority in economy of steam used for atomizing, the flat-flame type is often installed with Scotch boilers. Vice versa, round-flame steam atomizers may be used in water-tube boiler furnaces, but here the flat-flame burner is of undisputed superiority. A good burner of this type, properly operated, should not use over 0.35 pounds of steam per pound of oil atomized.

Steam atomizers (in fact all burners) were classified by Mr. Frank Van Vleck, Technical Secretary of the Liquid Fuel Board (see Board's report) and his work has been extensively quoted by writers on oil burning. As far as I know, the classification is not used in the "trade," and about all the distinction which is necessary in addition to "round and flat flame" mentioned above, is "outside mixer" and "inside mixer"; i. e., in one, the steam (or air) and oil come together outside the burner tip, and in the other, they are "mixed" inside the tip. There is little to choose between the two types, although the proportion of steam and oil, and the oil output, in the outside

mixer is very slightly affected by variation of the steam pressure—while on the other hand, any variation in the steam pressure in the inside mixer alters the rate at which the oil is delivered, as well as the proportion of steam and oil. But the main consideration in any burner is simplicity of design and ease with which it may be cleaned and repaired. Furthermore, the "atomization" of the oil in any burner, mechanical or otherwise, takes place at the orifice or outside of it and such things as "mixing" and "atomizing chambers" in the inner workings of the burner are mainly "talking points" for the salesman. The best steam atomizer I ever saw was made by Mr. Adam Heberer, of San Francisco, out of a simple piece of gas pipe—the only trouble with it was that it did not wear very well and was difficult to clean.

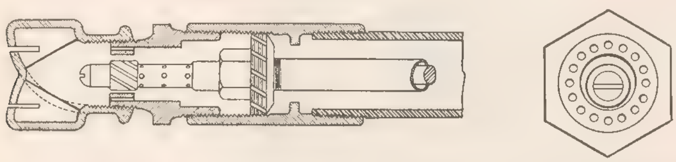


Fig. 19. Staples & Pfeiffer Flat-flame Inside-mixer Steam Atomizer.

A steam atomizing burner of the inside-mixing flat-flame type is shown in Figure 19. It is made by Staples and Pfeiffer, and has gained a good reputation in marine work on the Pacific Coast.

A type of outsider mixer is shown in Figure 20.

TYPES OF MECHANICAL ATOMIZERS AND METHODS OF ADMITTING AIR FOR COMBUSTION.

There are now so many successful designs of mechanical atomizers on the market that I am not able to include a description of them all in this paper. With some reluctance I have therefore decided to illustrate only those designs which have attained prominence in America. Many interesting inventions have been made abroad, notably in England, and there are many prominent names identified with the burning of oil fuel. However, all the oil burners work on the same general principle, and those used in this country will be sufficient to illustrate the state of the art. The following list is arranged in alphabetical order:

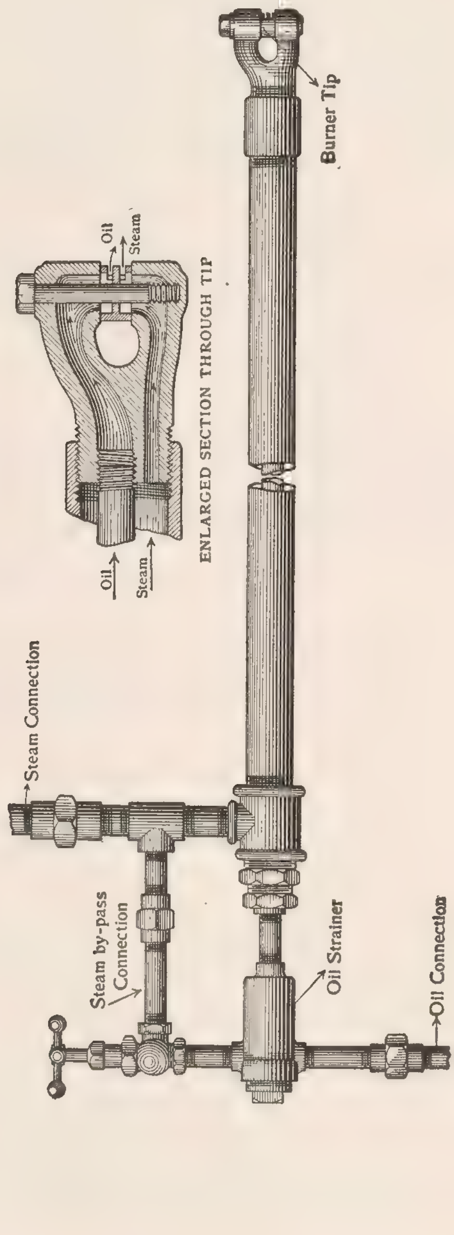


Fig. 20. Peabody Flat-flame Outside-mixer Steam Atomizer.

Bailey Burner. Made by the Newport News Shipbuilding and Dry Dock Company. This burner is shown in Figure 21. Mr. Bailey states that one of his assistants, Mr. Mortimer, was associated with him in the invention of this burner. A quick detachable coupling fastened with a yoke is used to hold the burner in position and a wooden handle may be screwed into the burner elbow to facilitate handling. A steel tube is screwed into the coupling casting and on the other end of the tube is screwed a composition nozzle which is adapted to receive a steel tip provided with a central chamber 3/8-in. in diameter. A special plug of adjustable length is screwed into the end of the chamber, so that the actual volume of the chamber in which the oil is given its rotary motion is adjustable. Grooves in the threaded portion of the tip are provided for delivering the oil under pressure to an annular space just outside the central chamber. Oil passes to the central chamber through two small openings or round channels drilled in the tip at an angle of about 45° to a plane at right angles to the axis of the burner. These channels are tangential to the sides of the central chamber, so that as the oil enters the chamber it acquires a rapid whirling motion and issues from the orifice in the tip in a finely divided conical spray. The Bailey design of air admission is shown in Figure 22 as attached to the Babcock & Wilcox Boilers of the Steamship "Matsonia".

This consists of a cast-iron grid of the shape of a truncated cone, the walls of which are cored so as to provide channels for the admission of the air. The passages are curved to give the air a rotary motion. Outside this grid there is a cover which may be revolved by means of a lever; this cover is slotted to correspond with the air passages in the truncated cone, and thus serves as a means for regulating the quantity of the entering air or for closing it off entirely. Inside the cast-iron grid there is another truncated cone of different dimensions designed to protect the tip of the burner from direct impact of the air; this is shown partly in section in the drawing. The burner is installed through the small end of the truncated cone, and in this particular design the burner is inclined slightly upward from the horizontal line in order to give an upward sweep to the spray as it enters the furnace.

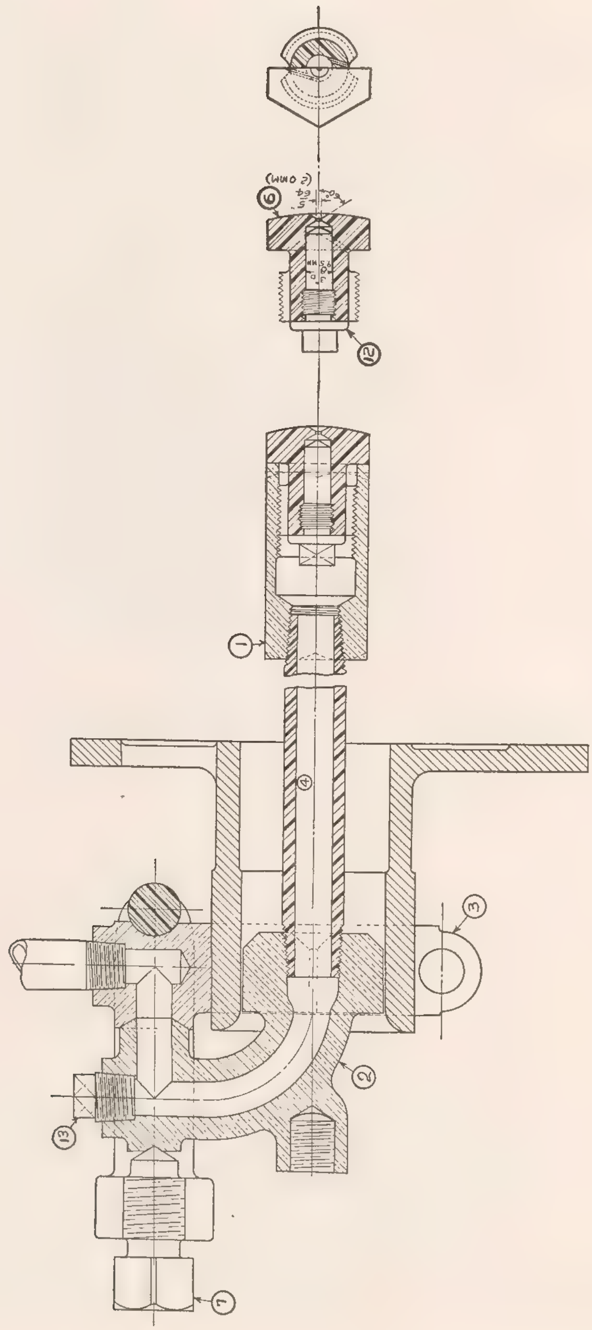


Fig. 21. Bailey Burner.

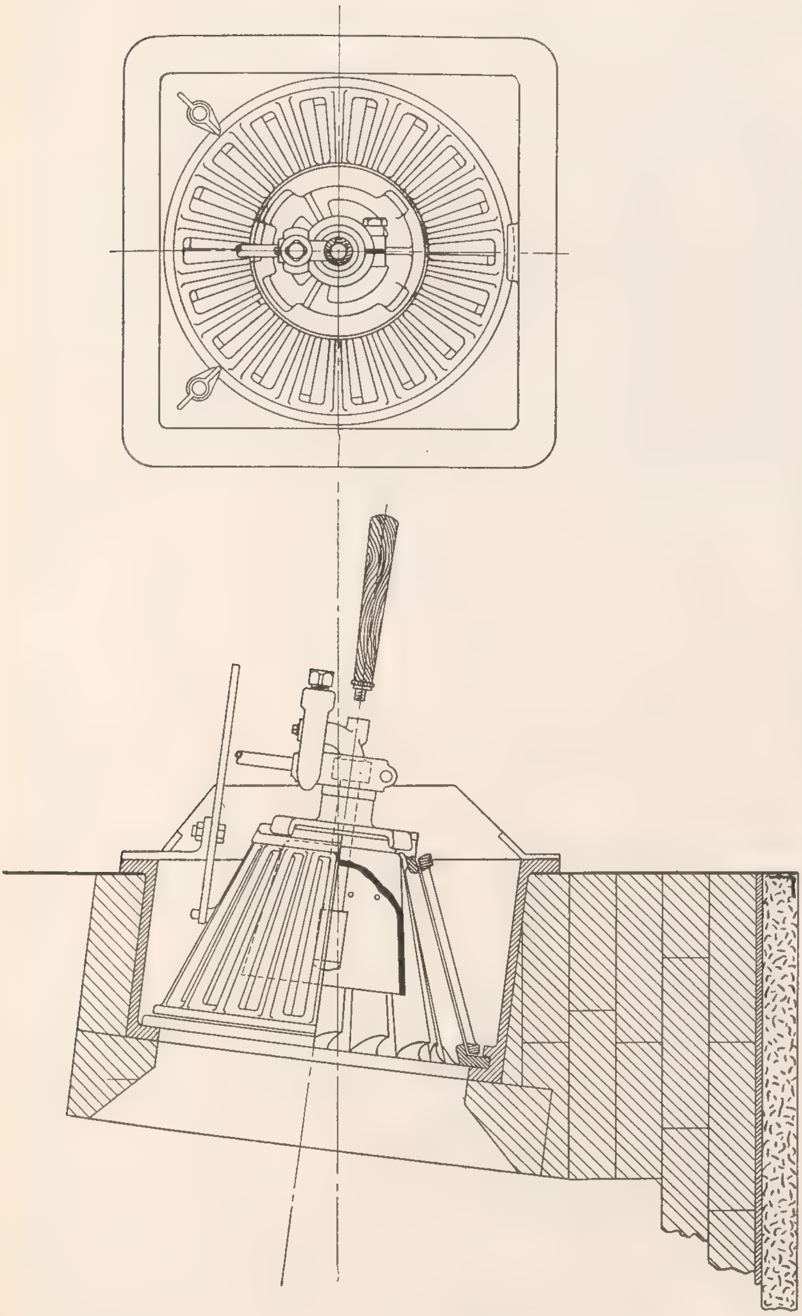


Fig. 22. Bailey Air Control as Fitted to the Babcock & Wilcox Boilers on the S. S. "Matsonia".

The design shown is adapted to operate natural draft, but it is also applicable to forced draft.

Bureau Burners. (Bureau of Steam Engineering, U. S. Navy.) The first Bureau Burner, Type Y (see Figure 23), was designed to be used at the Fuel Oil Testing Plant at League Island, where, after certain modifications made by Commander Hyland, it gave excellent results in the boiler tests at that plant. In this burner a quick detachable yoke coupling is used and also an oil strainer. A steel pipe connects the main body casting with the tip, which latter is also of steel, and like the Bailey burner is fitted with a plug, making the central chamber adjustable. Two small holes are drilled in the tip marked "AA" in the drawing, which deliver the oil under pressure to the annular space around the central chamber. This annular space connects with the central chamber by four holes drilled at an angle of about 26° with a plane at right angles to the axis of the burner, and tangential to the walls of the central chamber.

The Navy Department standard fuel-oil burner has recently been modified as shown in Type "I", Figure 24, this design originating with Lieutenant Starr, who succeeded Commander Hyland, in charge of the Fuel Oil Testing Plant. The quick detachable yoke coupling is retained, but the strainer is omitted and the oil passes directly into a heavy steel tube, the end of which is recessed to receive a steel plug which is chamfered, on the end which faces the tip of the burner, at an angle of about 26° with a plane at right angles to the axis of the burner. The extreme end of the plug is faced off smooth to give a flat surface which corresponds in diameter with a recess in the steel tip, which in turn communicates with the outlet orifice through a small conical chamber. On the conical face of the plug four grooves are cut which are tangential to the chamber in the tip. The oil reaches the outer ends of these tangential channels by passing through a hole drilled in the center of the plug which communicates with another hole drilled at right angles to same, thus delivering the oil to an annular chamber formed by a recess machined in the side of the plug. The steel tip itself screws on to the end of the oil pipe in such a way as to provide a large chamber to receive the

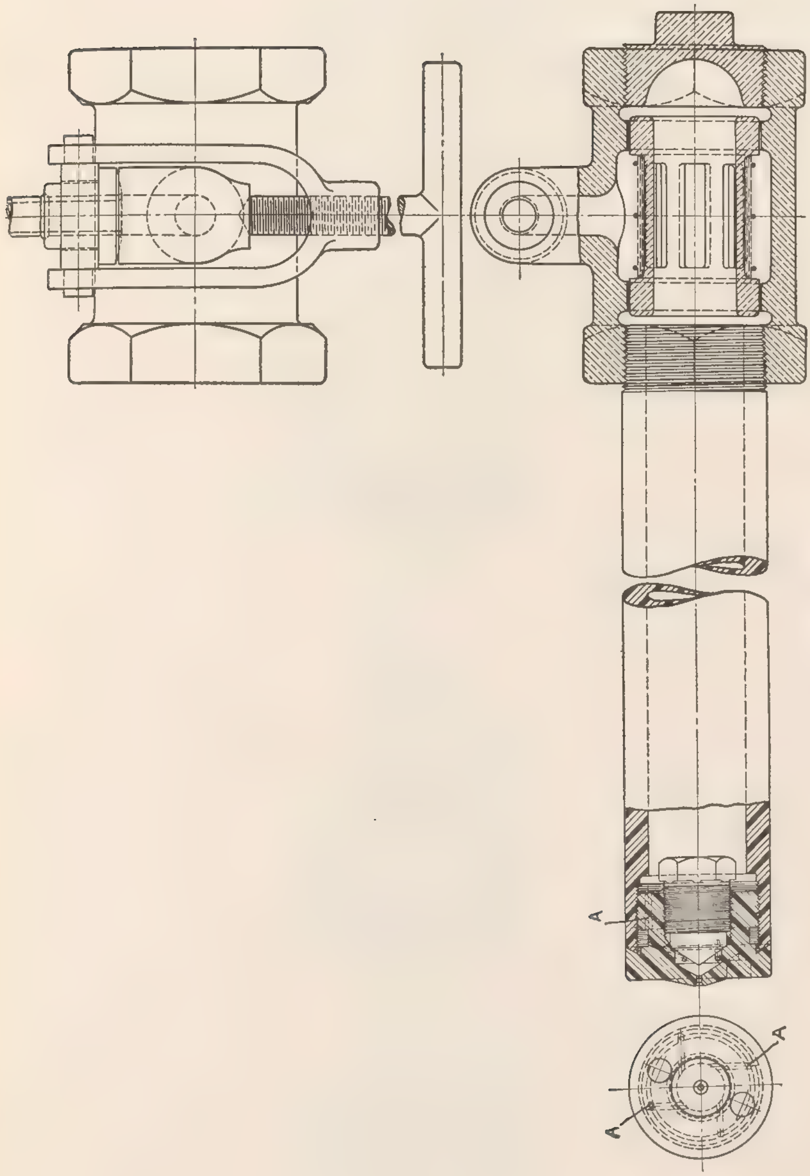


Fig. 23. Bureau Burner, Type Y.

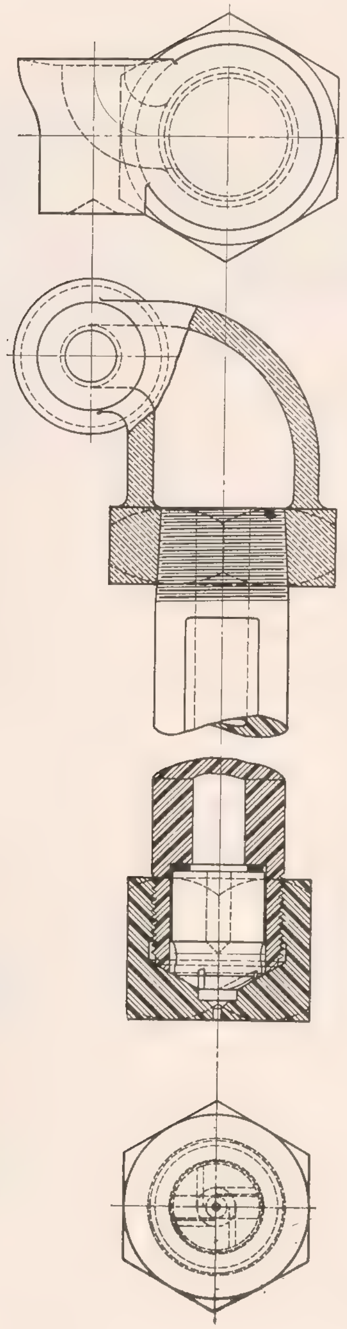


Fig. 24. Bureau Burner, Type I.

plug, which latter was originally intended to be movable in the direction of the axis of the burner, the idea being that this "floating" plug would be held tightly against the tip ordinarily by the pressure of the oil, but in case of dirt getting into one of the tangential channels, the pressure would force it through by driving the plug back slightly from its seat on the tip. In practice it has been found necessary, however, to use a small lead gasket to hold the plug firmly against the tip, as the oil pressure could not always be depended upon to do this. It will be noticed that this burner has the advantage over the previous design in that by removal of the tip (which, by the way, is made hexagonal in shape for the reception of an ordinary wrench and does not require a special tool, as in the case of the first design), the plug is at once removable and the tangential channels are exposed and are easily and quickly cleaned. Burners of this type are now being installed in some of our large super-dreadnaughts.

The Bureau design of air control as used at the League Island Testing Plant and perfected by Commander Hyland is shown in Figure 25, as adapted to a Babcock & Wilcox Boiler with double front. The air for combustion enters through suitable openings in the outer front fitted with doors which are arranged to close automatically in case of a flareback or excess pressure in the furnace. The air then passes into a conical cast-iron grid fitted with curved blades, the air inlet to the grid being controlled by a rotating shutter of suitable form on the exterior of the same. This is operated by means of a small gear wheel connected with a shaft which extends through the outer front and is provided with a handle, as shown in the drawing. The burner is installed through a sleeve which connects with the grid casting or may be made an integral part of same. It will be noted that the burner tip extends well into the interior of the cone and no protecting device around the tip is used. The Navy Department has granted permission to the ship builders or other interested parties for the free and unrestricted use of the Bureau design of burner and air control, and it is being fitted in many installations.

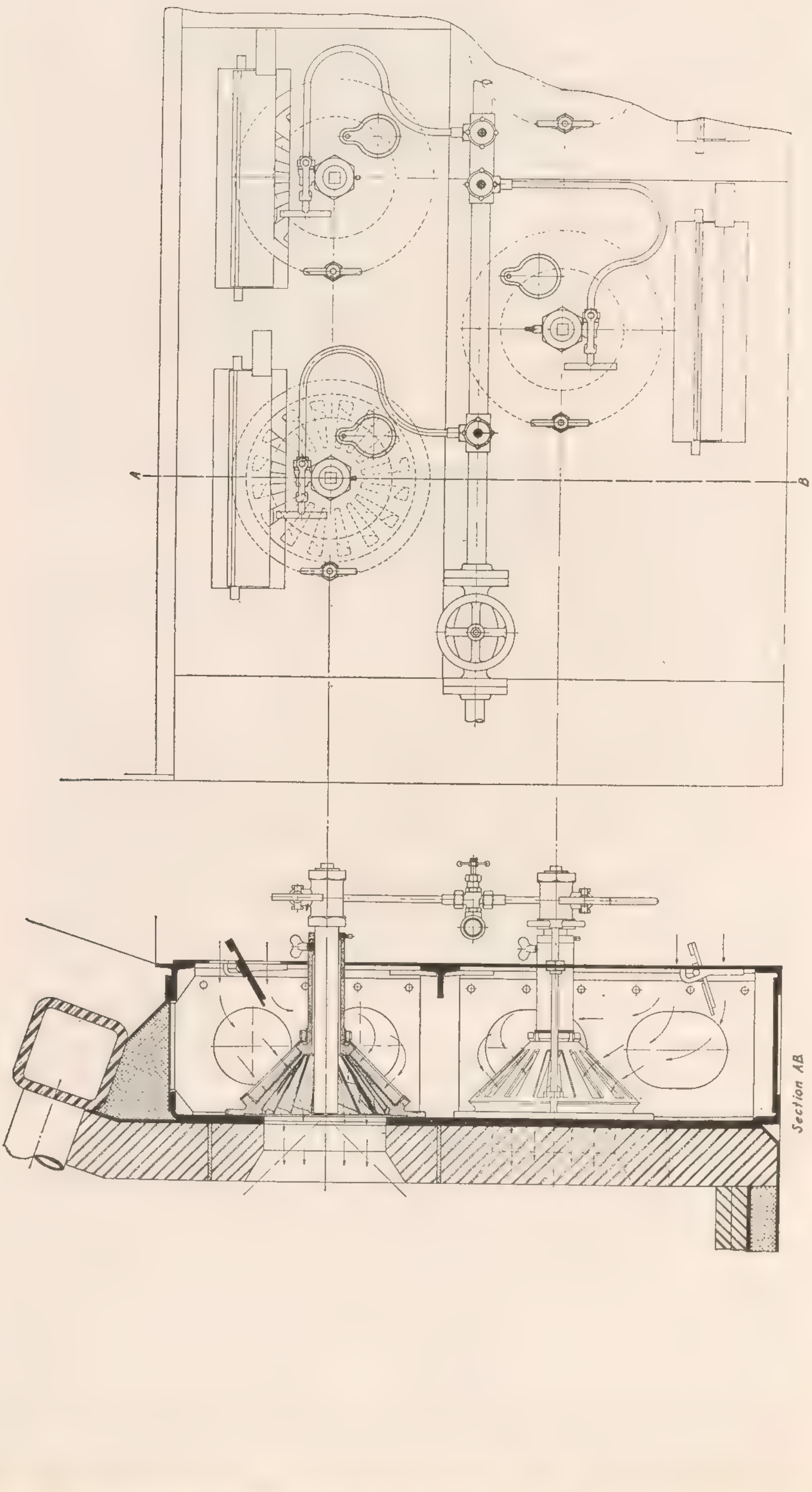


Fig. 25. Bureau Air Control Fitted to Babcock & Wilcox Boiler with Double Front.

Bath Iron Works. On the first introduction of mechanical atomizers this firm used the Normand burner and method of air admission in connection with Normand boilers installed on torpedo boat destroyers. They are now, however, using the Bureau burner and Bureau's design of air control.

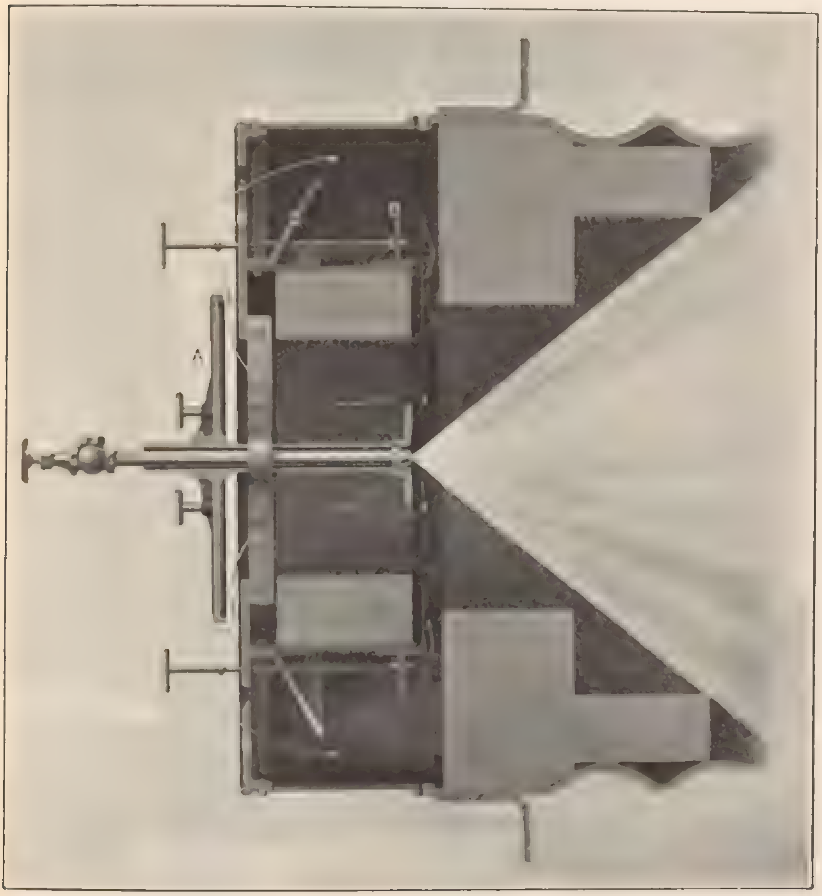


Fig. 26. Coen Burner and Air Control.

Coen Burner. The Coen Company, San Francisco, California. This burner and air control are illustrated in Figure 26. The burner is of the type which varies the output of oil by altering the size of the small tangential channels which deliver the oil to the central chamber. The main air admission, as is

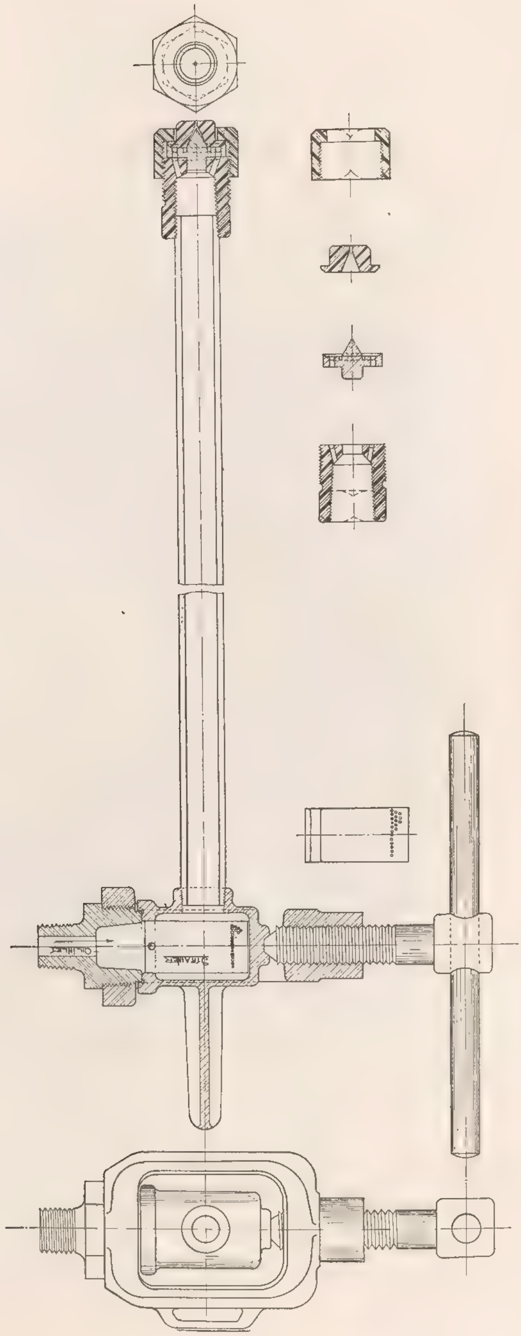


Fig. 27. Dahl Burner.

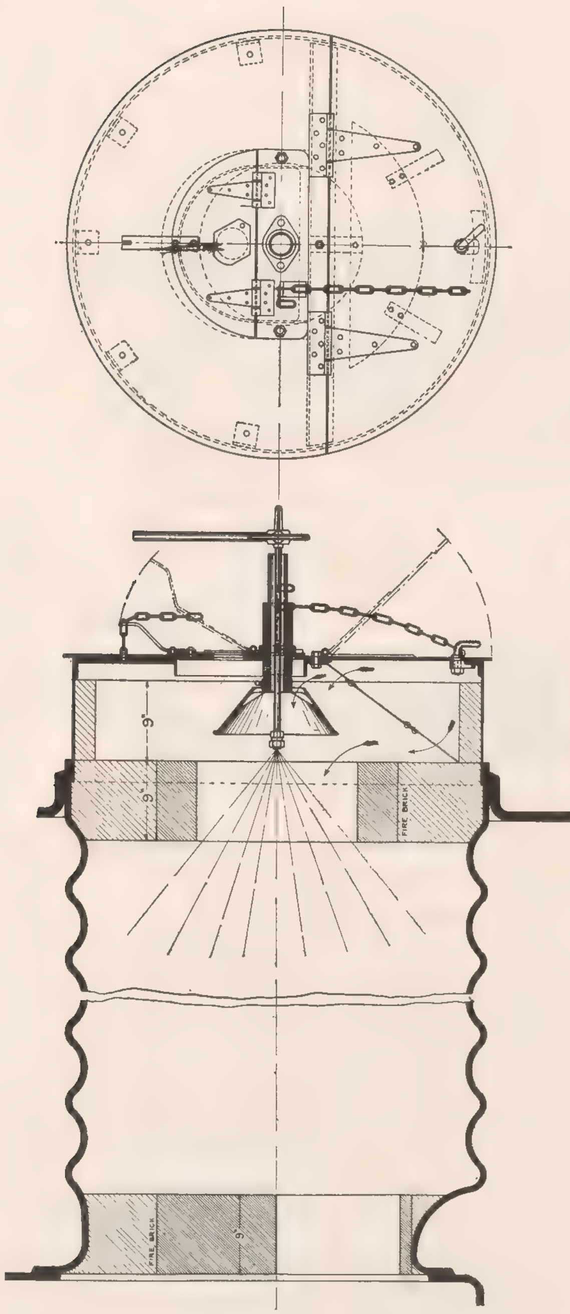


Fig. 28. Dahl Air Control.

clearly shown in the illustration, is controlled by an adjustable disc, while a supplementary air supply enters through the side of the cylindrical chamber in which the burner is placed, and which is controlled by a sliding cylinder. An adjustable disc or plate prevents direct impact of the air at the point where the spray leaves the tip.

Dahl Burner. Manufactured by the Union Iron Works, San Francisco. This burner has been installed in a great many merchant vessels operating on the Pacific Coast. The tip is shown in Figure 27, and it will be noted that the oil is delivered under pressure through tangential channels lying in a plane at right angles to the axis of the burner. The central chamber and tangential channels are made up

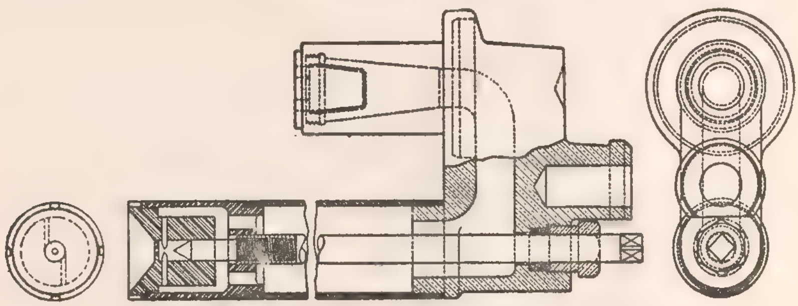


Fig. 29. Fore River Burner.

by a combination of two parts held together by a nut which screws on to the nozzle or the end of the oil delivery pipe. In fastening the burner in position, a quick-detachable coupling is used of the fixed-yoke type and an individual strainer of simple design is provided with the burner. The Dahl method of air admission is shown in Figure 28, illustrating the method of attaching to the furnace of a Scotch boiler. Air enters through furnace doors in the front of the furnace and passes around and through a conical deflector, which protects the burner tip from direct impact of the air; this deflector is adjustable in the line of axis of the burner. The spray is injected with the necessary air for combustion into the furnace through a circular opening in a brick wall suitably arranged.

Fore River Burner. Manufactured by the Fore River Shipbuilding Corporation. See Figure 29. An adjustable

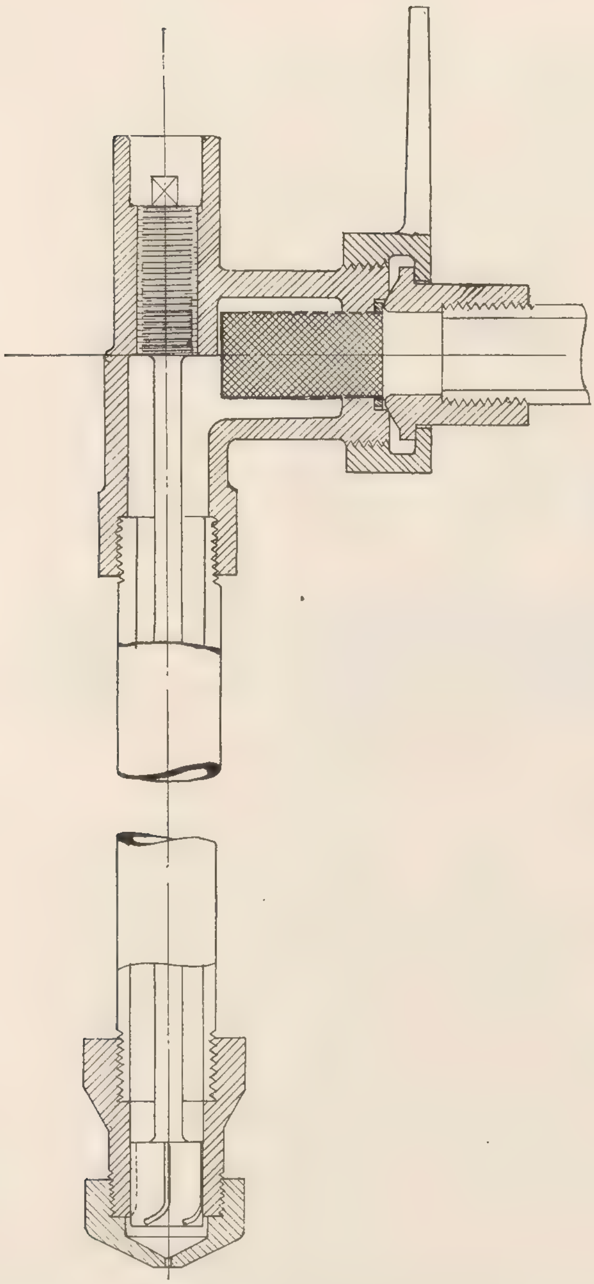


Fig. 30. Moore & Scott Oil Burner.

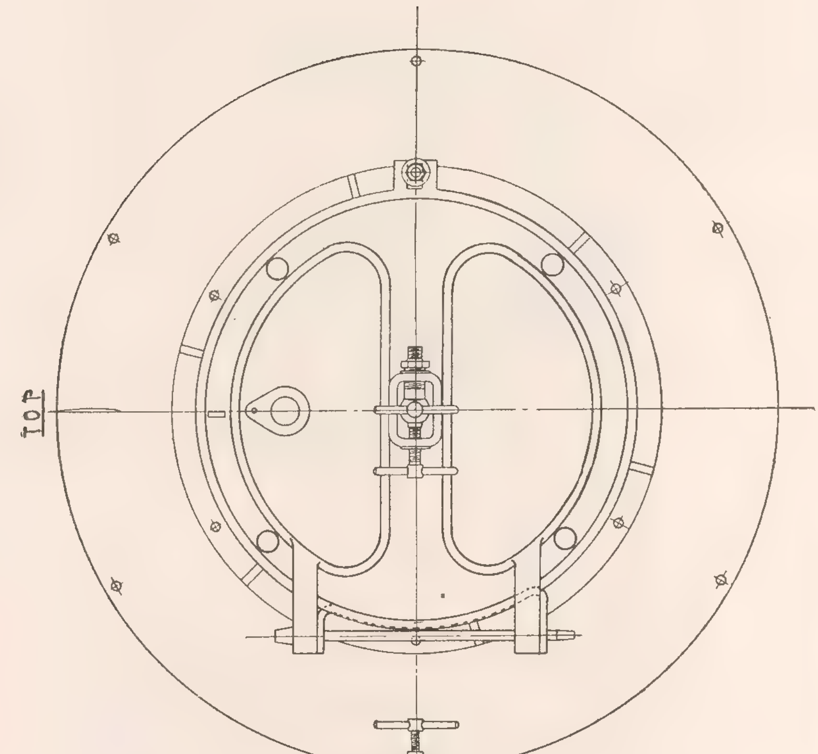


Fig. 31. Moore & Scott Air Control.

spindle in this burner is arranged to throttle or close the outlet orifice or vary the size of the central chamber to which the oil is delivered through two tangential channels. The burner is provided with a quick detachable arrangement for holding it in place. The tangential channels are in a plane at right angles to the axis of the burner. This company now uses the Bureau design of air control with all their oil burning installations.

The Moore & Scott Iron Works, San Francisco, manufacture a burner shown in Figure 30, in which it will be noticed that the oil is delivered to the chamber communicating with the discharge orifice, through oil passages cut in the sides and on the end of a plug which is adjustable in the direction of the axis by means of a spindle passing completely through the burner; a special strainer is used and the union for connecting the oil piping is fitted with a special means for detaching quickly. Figure 31 shows the method of arranging this burner

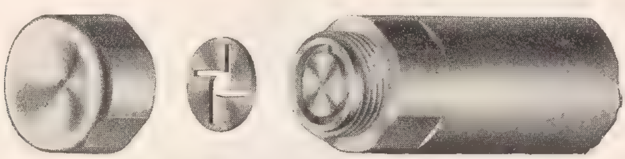


Fig. 32. Peabody Mechanical Burner.

for use in the furnace of a Scotch boiler and the method of admitting air for combustion.

Peabody Mechanical Burner. The illustration, Figure 32, sufficiently explains this burner, which was recently described in a letter of inquiry as "two nuts and a slotted plate, screwed on the burner barrel". In designing this burner the attempt was made to secure simplicity and to reduce to a minimum the surface with which the whirling oil is in contact. The central hole in the washer or disc is $\frac{1}{4}$ in. diameter and this corresponds in size to the base of the conical chamber in the tip; the entire space therefore in which the oil rotates is very small in volume. This burner is controlled and manufactured by The Babcock & Wilcox Company.

A large amount of experimental work in oil burning has been conducted by this company, the latest tests having been made with very low natural draft, with the method of

air control shown in Figure 33, this being the design of apparatus installed on the Coast Guard Cutter "Tallapoosa". The outer front plate of the boiler is omitted and each individual

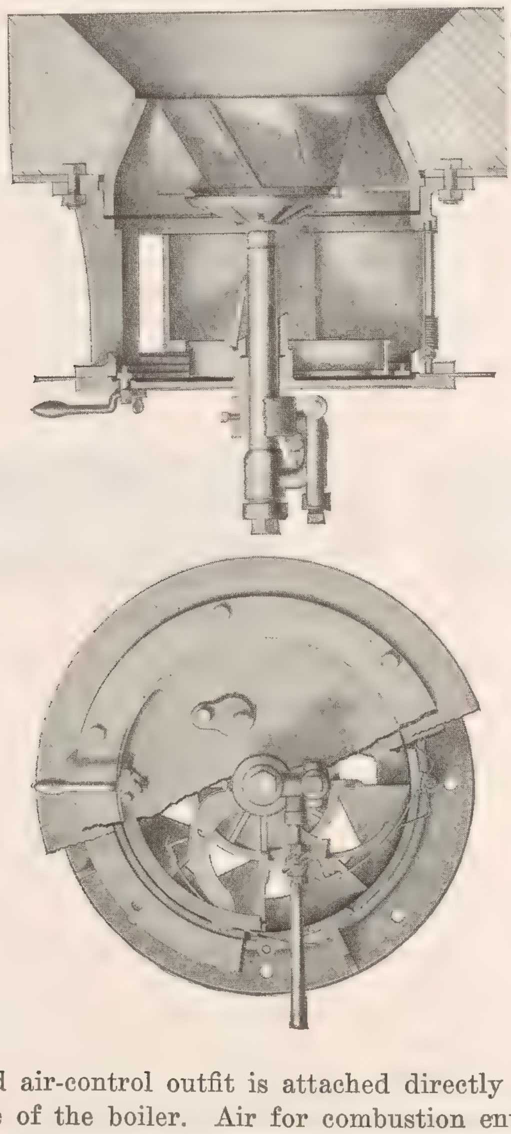


Fig. 33. Peabody Air Control.

burner and air-control outfit is attached directly to the main front plate of the boiler. Air for combustion enters through doors which are arranged to close automatically against any excessive internal pressure, but which may be regulated in the

matter of opening by means of a lever which operates a cam, as shown in the illustration.

Inside the housing, an impeller plate, which is characteristic of the Babcock & Wilcox apparatus, is placed in the center of the large end of the truncated cone of cast iron, and the burner is located in such position as to inject the spray through the center of this plate; the special blading of the impeller plate giving the air a rotary motion as it enters the furnace around the burner tip. The cone is fitted with blades so arranged as to give a rotary motion to the air, which enters around the edge of the impeller plate, this air being directed toward the axial line of the burner by the walls of the truncated cone. It should be noticed that one feature of this design is that the tip of the burner itself is always visible, so that the character of the spray can always be observed by the operator. For use with high forced draft the impeller plate has a fixed position with regard to the burner tip and is adjustable with respect to the truncated cone, i. e., the burner and the impeller can be moved in and out in the direction of the axis of the burner. The working out of this design and the excellent results, particularly the very satisfactory gas analyses obtained with it, are largely due to the ingenuity and untiring efforts of my colleague, Mr. Thomas B. Stillman, Jr.

Schutte-Koerting Burner. Manufactured by the Schutte & Koerting Company of Philadelphia. This burner is shown in detail, together with the method of admitting air for combustion, as applied to the Babcock & Wilcox boilers of the U. S. Torpedo Boat Tender "Melville", Figure 34A. A method of attaching the burner to a Scotch-boiler furnace is shown in Figure 34B. This burner is one of the few now on the market which depends upon forcing the oil through the helical channels formed by the thread of a screw in order to give it the necessary whirling motion. This principle was used in the early type of Koerting burner and is still retained. Very considerable designing skill has been shown in the method of attaching, arrangement of strainers, etc. The small spindle on which the thread is cut is faced at the end and rests in a steel tip adapted to receive it; a central hole in the body of this tip is counter-bored to give a conical chamber at the end of the thread, and this chamber

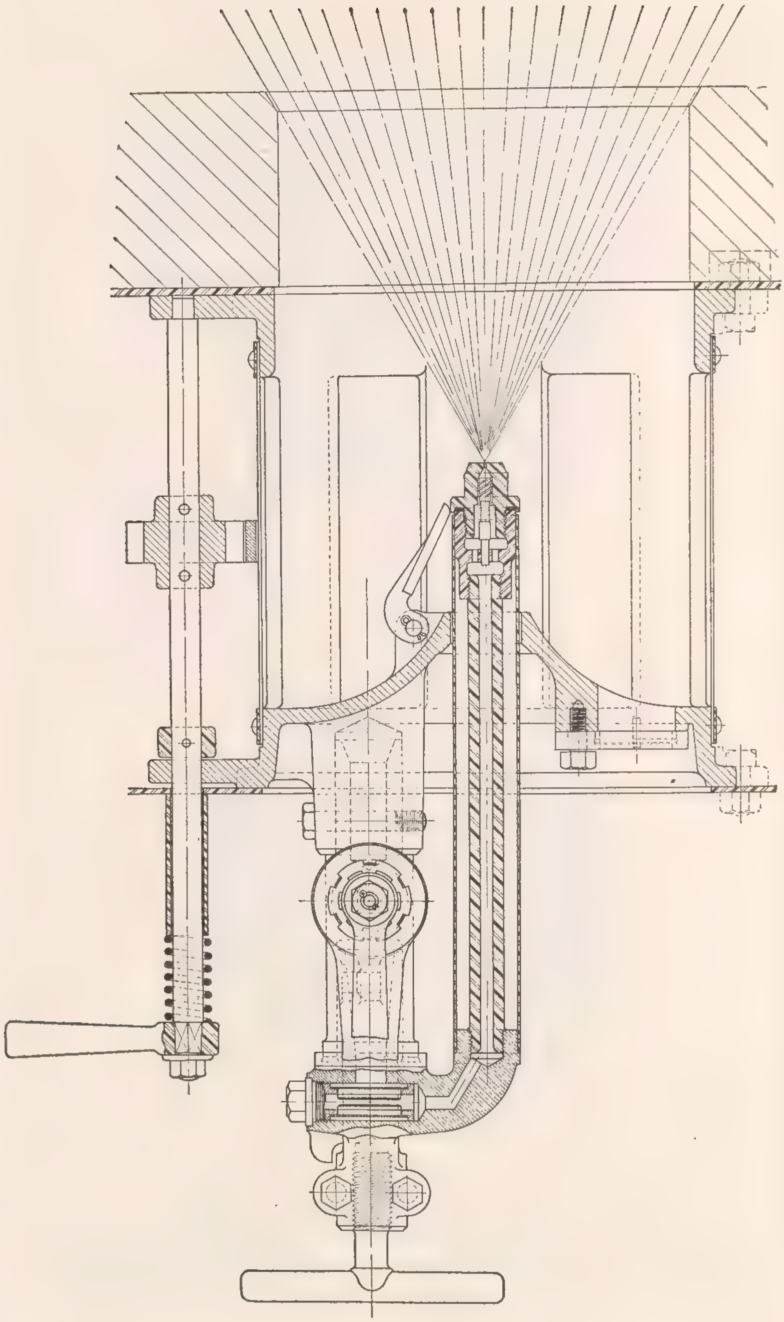


Fig. 34A. Schutte & Koerting Burner and Air Control as Fitted to Babcock & Wilcox Boilers of the U. S. S. "Melville".

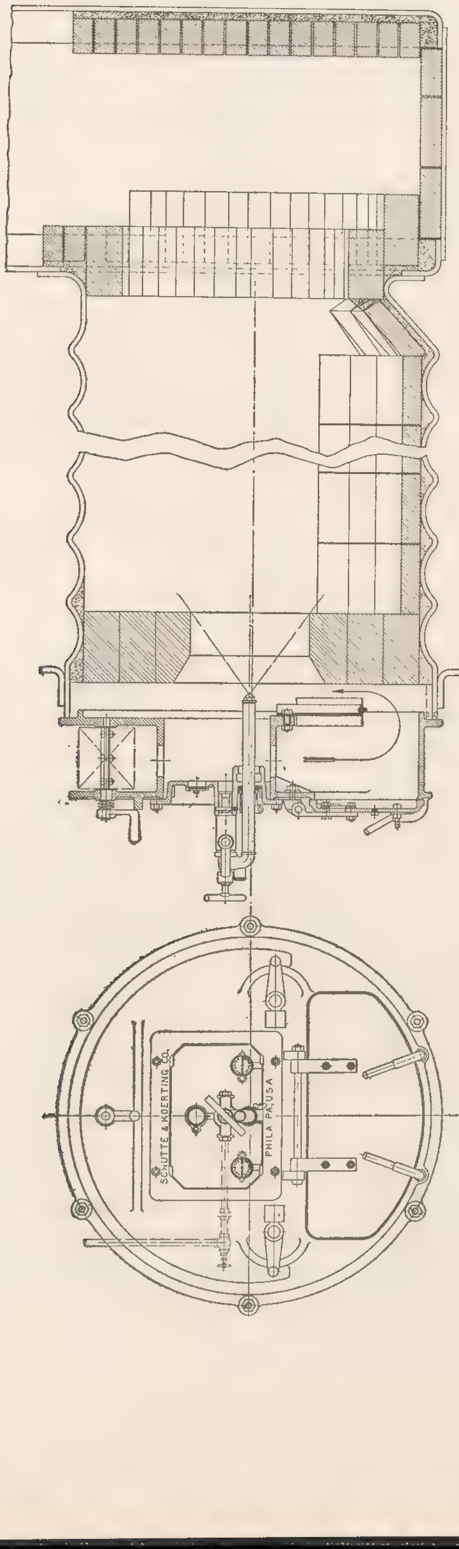


Fig. 34B. Schutte & Koerting Burner Fitted to Scotch Boiler.

communicates with the outlet orifice; the oil is therefore forced into the small conical chamber with the rotary motion due to the action of the thread. The end of the spindle opposite the helical thread is squared in section and fits into a square hole in the nozzle of the burner, which prevents the spindle from rotating when in operation.

The air admission chamber is cylindrical in shape and is provided with longitudinal openings parallel with the axis of the burner, which admit the air for combustion. These openings are covered by an adjustable sheet-iron cylinder, which fits on the outside, and the air is controlled by rotating this cover. The air is not given a whirling motion. In order to obtain the best mixtures and prevent pulsations, a high air pressure is usually carried and the air forced through restricted openings at high velocity.

White Burner. This burner is manufactured by the Washington Engine Works, New York. See Figure 35. It has been installed extensively in merchant vessels on the Atlantic Coast and has met with pronounced success, largely due to the personal efforts of Mr. William A. White, the inventor and president of the company. The mechanism for giving the oil a whirling motion consists of a plug which seats against the inner surface of the tip and is held in position by a spring. Oil passes along the grooves cut in the cylindrical portion of the plug and then along the corresponding grooves cut in the conical end, which are so arranged as to deliver the oil tangentially to the central chamber in the tip and at an angle of about 45° to a plane at right angles to the axis. The design of this burner is simple and well worked out, as will be evident by an examination of the method of attaching the burner to the front, quick-detachable yoke coupling and strainer. The method of admitting the air for combustion used with the White burner is shown in Figure 36. The air passes into the hollow furnace front through ducts which give it a rotary motion, and the metal work of this part is intentionally exposed to the radiant heat of the furnace for the purpose of heating the air before it enters the furnace. The flaring sleeve around the burner is adjustable in the line of the axis of the burner and it will be noticed that a small

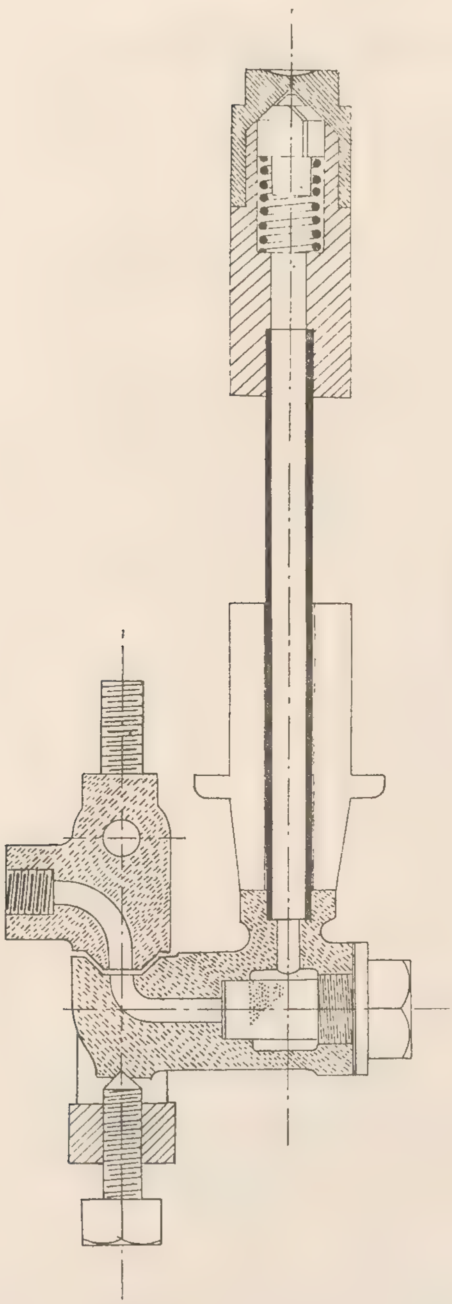


Fig. 35. White Burner.

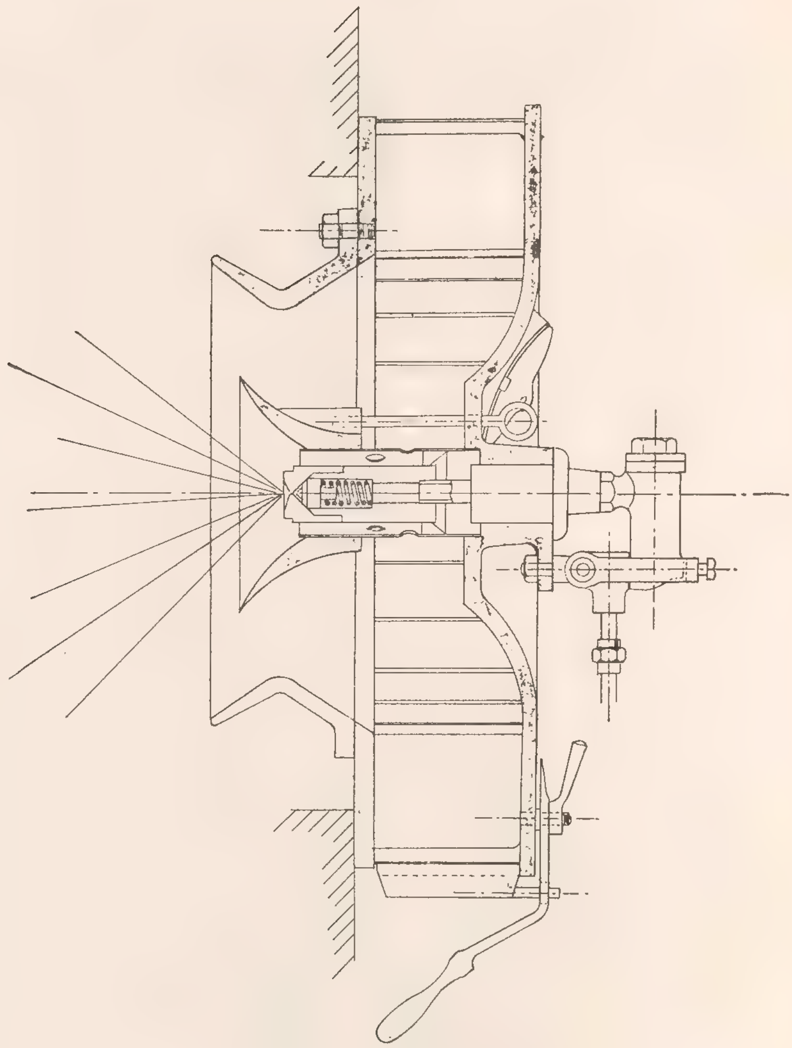


Fig. 36. White Air Control.

amount of air is admitted directly around the tip through the opening in the sleeve. It is claimed that the "Venturi meter" effect of the portion of the apparatus where the air enters the furnace is of benefit in promoting combustion. The White burner attached to the furnace of a Scotch boiler is shown in Figure 37, and it will be noticed that no brickwork is used in the furnace; and the inventor claims also that retarders are not nec-

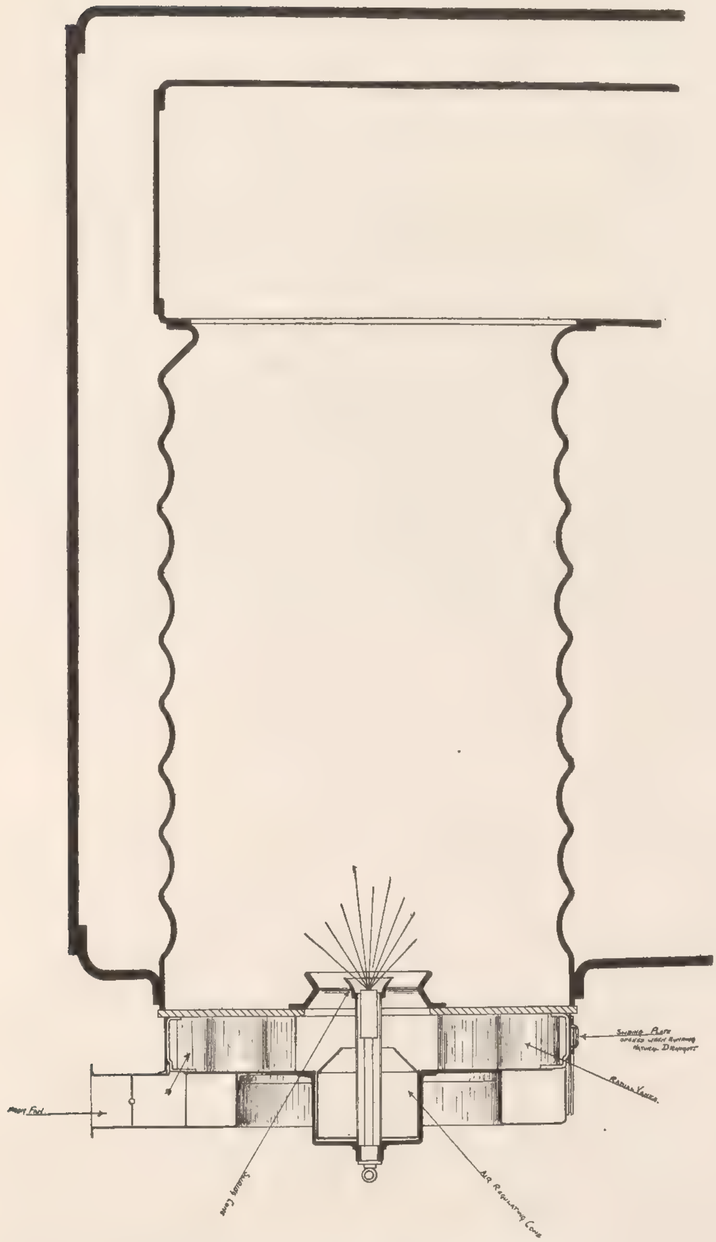


Fig. 37. White Burner Fitted to Scotch Boiler.

essary in the tubes of the Scotch boiler when using his system. It may be noted here that brickwork in the furnace of Scotch boilers using oil fuel is usually installed because it is supposed to give better economy; the same thing may be said of retarders in the boiler tubes.

An inspection of the various burner designs described above will indicate a preponderance of the type in which the oil is delivered not only tangentially to the walls of the central chamber but at an angle to a plane at right angles with the burner axis. The prevalence of this idea suggests the possibility of its possessing some inherent advantage. We have not been able to find this in our experiments and we adhere to the flat-disc design delivering oil tangentially to the central chamber in a plane at right angles to the axis of the burner: First, because it is simpler; second, because we believe it gives a finer spray, which is an advantage rather than otherwise; and third, because the net effect of the angular delivery is to increase the output of the burner for a particular size of orifice and at given oil pressures and temperatures. We prefer, if greater burner output is desired, to increase the diameter of the orifice. In fact, one of the disadvantages of the mechanical burner is the very small orifice in the tip, so that, other things being equal, the bigger the orifice the more practicable the burner.

AUTOMATIC CONTROL.

Oil fires when properly handled by careful operators result in efficiencies very much above those obtainable with coal, for reasons which are obvious. On the other hand, the tendency of human nature at large seems to be to make the easy thing easier, and it is distressing to note the frequent carelessness and utter disregard of economic conditions by those in charge of the operation of oil burners. And it should be realized, too, that the extremes to which poor firing with oil can go, when neglected or improperly handled, are limitless. A coal fire can get just about so bad and then it will go out altogether. But an oil fire will keep on burning under the most adverse conditions and there is almost no end to the amount of fuel that can be wasted. A reliable automatic device for properly controlling the oil burner and air admission would in many

cases be beneficial; but, like all automatic devices, it would have to be watched by a good man, and I am disposed to think that it is about as well to permit the good man to watch the fires. Particularly is this view strengthened when the difficulties of the problem of automatic control of oil fires are considered, as well as the danger of leaving oil sprayers at the mercy of pilot lights.

Atchison & Weymouth of San Francisco have patented an automatic control for steam or air atomizers. The burners and the boiler damper are operated by mechanism controlled by the steam pressure. This has been applied successfully, I understand, to shore plants. The Lalor System also has attracted enough attention to be specified by the Army Engineer Department, but I believe no installations are yet in service.* The Lalor cut-out valve for closing off the oil in case of a breakage in the oil line or at the burners has been used in several installations in the Navy, but the complete Lalor automatic control has not been found suitable for Naval service.

The field is a fair one for inventors with sufficient courage, and complete success would be welcome.

FORCED DRAFT—BLOWERS.

While excellent natural draft results may be obtained with oil—both with steam and mechanical atomizers—the high boiler capacities which may be developed with this fuel require high forced draft.

For maximum conditions, the closed fireroom is essential and is employed entirely in destroyer and other high-speed vessels. Electric- or turbine-driven high-speed fans are used and no difficulty is experienced in obtaining 6 in. and even 8 in. of air pressure measured by water column.

Where high boiler capacity is not needed, but where natural draft conditions are not quite sufficient, the burners and air-controlling devices may be housed in, and air under moderate pressure delivered into this casing, either by individ-

* Since this paper was written the U. S. Army Dredge ''Comstock'', fitted with the Lalor system, has been placed in commission after successful trials.

ual fans or by ducts. Figure 38 shows for illustration an arrangement of this kind used for Scotch boilers by Mr. White. It is also applicable with slight changes to water-tube boilers. The Babcock & Wilcox Company have employed this method of draft with satisfactory results.

The standard Howden heated-air system, which is so useful for Scotch boiler installations, is easily applied to use with oil fuel. Also owing to the relatively low uptake temperatures

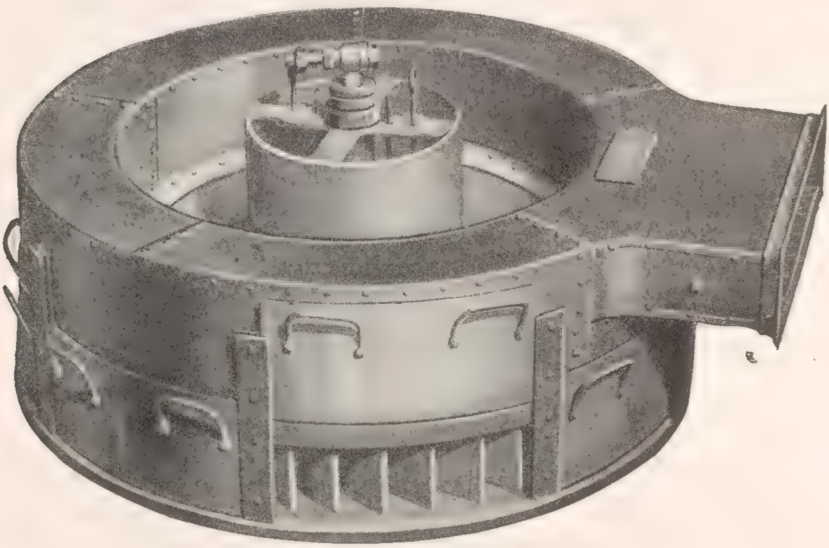


Fig. 38. White Forced Draft Housing for Scotch Boiler Furnace.

with oil as compared with coal, the so-called "induced-draft system" is especially suitable—particularly with boilers similar to the B. & W., in which the gases leave the boiler at temperatures so low as to make the use of air heaters or economizers in the uptake hardly of sufficient value to cover the cost of installation. Induced draft has all the convenience of natural draft in the matter of handling the burners.

The "pressure blowers" for use with air atomizers requiring 6 to 8 ounces pressure, once a considerable source of trouble, have passed away as burners of the mechanical type have been more widely introduced.

FURNACE DESIGN.

In many respects the water-tube-boiler furnace is better adapted for oil burning than the Scotch-boiler furnace; thus the larger amount of incandescent brickwork is an aid to combustion and the size and form of the furnace may be proportioned to still further promote the burning of the oil.

This is not to say that excellent results are not obtained with Scotch boilers using oil. This is a matter of common record, especially when retarders are used and the boilers operated with Howden draft, which saves heat not absorbed by the boiler and returns it to the furnace. In this connection it is worthy of remark that methods of heating air for combustion directly from the furnace itself have no value from the point of thermal efficiency, except possibly in cases where very small or overcrowded furnaces make it desirable to promote the rapidity of combustion, when the heated air may be of some slight advantage. It is of course true that heating the air by bringing it in contact with side casing or boiler-front plates which are insufficiently lagged may save some heat which would otherwise go to waste; but deliberately reducing the lagging for the purpose of heating the air is only "robbing Peter to pay Paul", and further, it results in undue losses through radiation during "stand-by" periods. The best practice is to properly protect the boiler against radiation losses and avoid complications installed for the purpose of heating the air, unless the source of heat is from the waste gases.

It has long been recognized that the type of burner, while important, is of less significance than the size and general design of the furnace. In those cases, now becoming rare, where the oil is atomized to the point of giving "flameless combustion", furnace design does not require so much care; but where a flame exists, it must be prevented from localizing on the boiler surfaces and the gases must be kept highly heated and given time and space in which to burn as completely as possible before being brought into contact with the boiler. Air admission and control are of prime importance, and the round-flame mechanical atomizer particularly requires special means for mixing thoroughly and evenly the minimum amount of

air with the oil spray; also, as the gases expand and burn they require more room.

The best furnace conditions for burning oil are so well represented in the furnace of the Babcock & Wilcox marine boiler

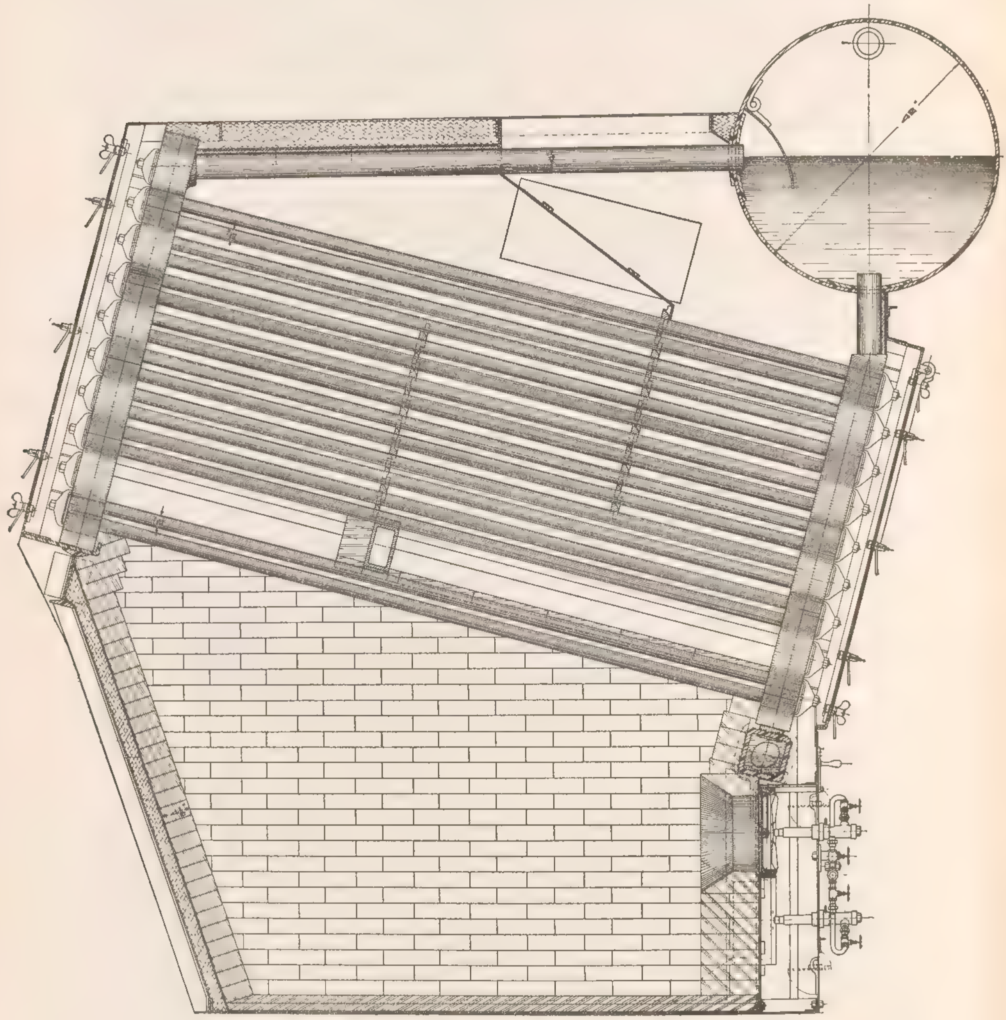


Fig. 39. Furnace of Babcock & Wilcox Marine Boiler.

that I give herewith a sectional view of one of the boilers of this type installed in the U. S. Oil-burning Tanker "Arethusa", Figure 39.

The reverberatory brick baffle on the bottom group of tubes directs the gases to the rear of the furnace, in which direction it will be noted that the furnace increases in height and volume. Furthermore, the oil is injected into the furnace along lines nearly parallel or at a slight angle with the tubes, which promotes a very even distribution of the flame along the bottom row of tubes.

The importance of the principles involved in this design are further emphasized by the fact that an adaptation of them

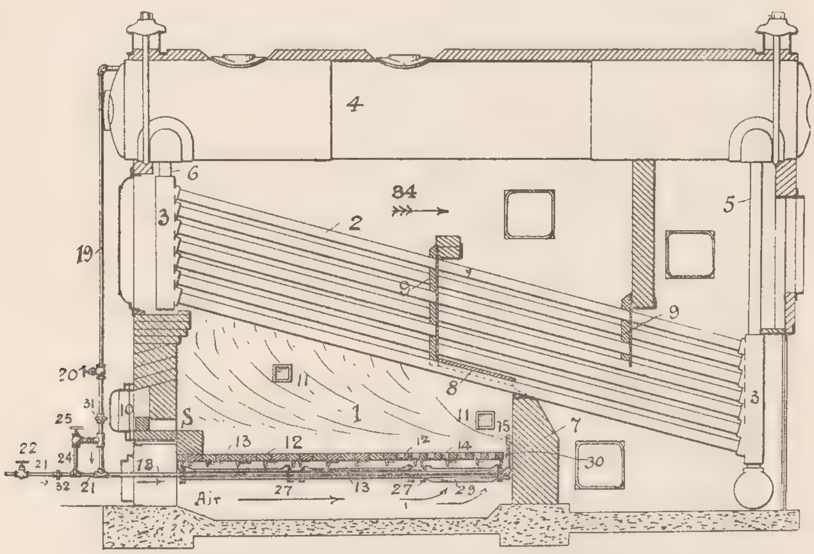


Fig. 40. Standard Babcock & Wilcox Oil Furnace for Stationary Boilers (Peabody Patent).

is used by The Babcock & Wilcox Company in their standard oil-burning furnace for the stationary or land-type of boiler. This is shown in Figure 40, reproduced from the patent drawing, and it will be noticed that the burner tip is located at the small end of the furnace, which thus increases in height and volume in the direction in which the oil is injected. This is the first application of what has come to be known as the "rear-shot burner", a device which has been imitated many times owing to the very high results in capacity and economy obtained with this furnace arrangement.

Mr. Charles P. Wetherbee, Vice-President of the Bath Iron Works, makes a most interesting point, indicating that in furnaces of special forms, such as that in the Normand boiler, the degree to which the oil is atomized has a marked effect on the distribution of the gases, and that the finest atomization is not desirable. This apparent anomaly has been noticed by others operating this general type of boiler and seems to be an established fact.

Mr. Wetherbee writes:

"We are using the Bureau of Steam Engineering standard burners, but our Chief Engine Draftsman, Mr. Bimson, has made a lot of experiments with them and has obtained curves for varying the proportions of the tips so that we can get any desired angle of oil cone, fineness of oil spray and quantity of output.

"We found that the exact figures given by the Bureau of Steam Engineering gave too wide an angle of oil cone and too fine an atomization, with the result that the furnaces had very hot fronts and cold backs, and we got no steam.

"We find that when the oil is atomized coarsely enough to burn all the way back to the back wall we get better combustion and much more steam."

The furnace brickwork in water-tube marine boilers must be constructed of the best material obtainable, owing to the high temperature in the furnace. In Scotch boilers, less care in selecting the brick is permissible, as the brickwork usually installed is limited to the front of the corrugated furnace, which remains comparatively cool, and to a small patch of flooring in the furnace under the oil spray to catch drippings and assist in igniting the oil, and to a ring of brickwork at the throat of the furnace at the combustion chamber end, and to the back of the combustion chamber itself. At the three points last named the brick is prevented from becoming excessively hot by contact with the water-cooled surface of the boiler. The water-tube-boiler furnace has no such protection for the bricks, the brickwork being a protection for the casing. Thus, these brick must stand the high temperature of the furnace of this character of boiler, which may reach 2800° to over 3000° F.*

* Since the above was written The Babcock & Wilcox Company has completed some exhaustive experiments with oil fuel, made for the purpose of thoroughly testing out various combinations of material for furnace lin-

In boilers of the "destroyer" class, which are built very light, strong thin tiles of special shape are used and bolted to the casing. The brick are usually cored out to still further reduce weight. It is preferable, where the nature of the service permits of greater machinery weights, to use regular 9-in. fire brick and make side and rear walls at least 9 in. in thickness. In such walls, bolts are usually not required. In any case these bricks should be backed by 2 in. to 3 in. of non-conducting material between the brick and the casing plate. Magnesia is frequently used for this purpose, but it is very unsatisfactory owing to its shrinkage when heated. We are now looking for an acceptable substitute.

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ings for marine boiler work. The tests were made at high capacity and each was of 36 hours' duration, to thoroughly "saturate" the material with heat. Furnace temperatures exceeding 3200° F. were observed when the excess air for combustion was reduced to a minimum. Fire-brick sufficiently refractory for this work are obtainable from a number of sources, but care must be taken in the case of tiles bolted to the casing to keep the bolt far enough away from the furnace side of the brick to prevent iron oxide from forming and making a flux with the silica of the brick. This quickly destroys the wall.

It was found that pulverized fire-brick made a good intermediate layer in furnace floors, being a much better heat insulator than the solid brick, and of course highly refractory. The most satisfactory insulating material, however, and one sufficiently light to make an excellent substitute for the 85% magnesia block used heretofore is that which has as a basis a substance variously known as diatomaceous earth, *Kieselguhr* (from the German words meaning "flint-sediment"), Sil-O-Cel, and sometimes as "infusorial earth"—though the latter term refers more particularly to beds of the minute shells of "infusoria", a low order of animal life, while diatomaceous deposits consist of the remains of infinitesimal aquatic plants known as diatoms. Under the title, "The Kieselguhr Industry" (Metallurgical and Chemical Engineering, February, 1914), Mr. Percy A. Boeck gives an interesting account of this material and its uses.

The value of the material as an insulator against heat lies in the fact that the tiny plant shells which are about 90% silica, and thus highly refractory, are filled with minute air cells or voids in almost countless numbers. In an article on "Infusorial Earth", Mr. Samuel H. Dolbear states that 40,000,000 diatoms may be packed in a cubic inch. The minuteness of the air cells may therefore be appreciated.

Diatomaceous earth is prepared for use as an insulator in various ways, one convenient form being that known as Nonpareil High Pressure Block, made by the Armstrong Cork & Insulation Co., in which asbestos fibre and some lime as a bonding material are used in combination with the earth.

In laying up brick walls and flooring of oil furnaces, provision should be made for expansion, but it is worth noting in this connection, that there is a great difference in the coefficient of expansion of fire brick. It is possible to secure highly refractory brick and tiles made of material which expands but slightly, not over $\frac{1}{16}$ in. in 9 in.

The Babcock & Wilcox Company uses a light wash for making joints, composed of 15 parts (by weight) of fire clay, 5 parts of carborundum sand, and 1 part silicate of soda. The special high temperature cements on the market are a needless expense for new work but are very effective for repairs, where they find a special field of usefulness.

It is a good idea to throw a few old glass bottles into the furnace to make a glaze on the bottom surface and fill the cracks.

FURNACE VOLUME.

In the burning of oil, "furnace volume" has the same significance that "grate surface" possesses in coal-burning installations. Strictly speaking, "effective furnace volume", or that actually occupied by the burning gases, is the volume which should be considered. This is somewhat indeterminate, however, and the proportion of the full volume actually utilized varies in different types of boilers. It is customary, therefore, to base calculations on the total volume of the combustion chamber, making an allowance where data are available for special furnace designs in which more or less of the total volume is utilized. In the Scotch boiler furnace, little attention is paid to volume: first, because the boilers are not forced to the same extent as are water-tube boilers, and, second, because usually one burner is installed per furnace and the proportions are more or less left to take care of themselves—large-diameter furnaces generally being preferred, especially for forced draft.

But in water-tube boilers the conditions are different. Almost without exception the burners all discharge into a common combustion chamber, and conditions are at once encountered which do not enter into the problem of the "one-burner-one-furnace" arrangement of the Scotch boiler. Thus, there may be interference between the flames from adjacent burners,

and undoubtedly eddies of gas occur in the furnace which affect air admission and control, although not wholly indicated by the draft gage. For instance, in a furnace fitted with, say, four burners, properly spaced and provided with proper means for air control, each burner being surrounded by a fixed area for air admission, and having a furnace volume equivalent to, say, 60 cubic feet per burner and operating at a fixed draft of, say, ½ in. at the damper, a certain maximum boiler capacity is obtainable when operating all four burners. This cannot be increased 25% by installing a fifth burner of the same size and with like air opening. In fact, under the particular conditions named, while there will be some increase, the actual gain in boiler capacity will be very little, although the burner oil-atomizing capacity and the area for the intake of air for combustion have been increased 25%. This is because the oil which can be burned per cubic foot of furnace volume has a certain limit for a given draft and cannot be increased beyond that limit by the further multiplication of burners, even when accompanied by increased opening in the boiler front for air admission. The draft gage does not explain this, as the draft is kept constant at the damper and the furnace draft will be reduced but slightly on the firing up of the fifth burner. On the other hand, if three burners are installed instead of four, keeping the size the same and the air openings the same per burner, the boiler capacity obtainable will be very much more than three-quarters of that previously obtained with the 4-burner equipment; for here each burner has a furnace volume allotted to it of 80 cubic feet instead of 60, and it will be found that the oil which can be burned per burner will be materially increased and there will be a tendency to approach the same rate of combustion of oil per cubic foot of furnace as before. Thus, the analogy between furnace volume and grate surface will be obvious, though the size and number of burners and the air admission area are qualifying factors.

An interesting point we have noticed in our experiments is the fact that the actual limit in the rate of combustion of oil per cubic foot of furnace is apparently a matter of heat units rather than pounds of oil; or to put it another way, the boiler capacity obtainable under given conditions of burner equip-

ment, furnace volume and draft, seems to be more or less independent of the quality of oil, i. e., more oil of poor quality can be burned without smoke than of the richer oil. The total number of heat units evolved, however, in a given time is approximately constant. The net result is that just as high boiler capacity can be obtained with a given draft with good oil and bad oil. I am not ready to say that this will not have decided limitations, but the indication is that larger furnaces will not be required for poor oil.

AIR FOR COMBUSTION—UPTAKE AREA.

The air required for complete combustion varies with the composition of the oil. Approximately, however, it may be considered about 14 pounds of air per pound of oil or about 183 cubic feet at 60° F.

The nature of the fuel and methods of burning it permit the excess air required for complete combustion in the furnace to be reduced very greatly—tests having shown less than 10%. This means that the air actually required per pound of oil, under the best conditions, will equal about 200 cubic feet at 60° F. A liberal allowance over this figure should be made when figuring sizes of blowers, air ducts, etc., as test conditions cannot be maintained in practice.

While it will be evident that uptake and funnel areas can be made smaller for oil than for coal, it must be remembered that for each pound of oil burned, about one pound of steam is formed in the furnace due to the combustion of the hydrogen. This passes away through the uptakes and funnel as superheated steam.

The United States Navy has fixed the areas of funnels in recent installations as 1 square foot for each 300 pounds of oil burned per hour. This proportion has been reduced to 1 square foot for each 375 pounds of oil burned per hour in "destroyers", which have short uptakes and funnels. These areas, while adequate for naval vessels which operate at maximum power only under forced draft conditions, should not be taken as a criterion for merchant service. A safe rule would provide 1 square foot cross sectional area of funnels for each 200 pounds of the maximum amount of oil burned per hour.

NUMBER OF BURNERS PER BOILER.

The less the volume of combustion space provided per burner, the less the ultimate capacity per burner in pounds of oil burned (or as elsewhere noted, B.T.U. evolved), under fixed conditions of draft. This falling off in maximum individual burner capacity, as the number of burners per furnace is increased, is in less proportion, however, than the increase in the number of burners, assuming that the total furnace volume and the draft remain constant, so that up to a certain point the ultimate boiler capacity obtained with a fixed draft is increased by using a larger number of smaller size burners. The increments grow less and less, however, as the limit is approached in the rate at which the oil can be burned. This limit increases with the draft, and for approximate values, with a draft at the damper equal to ¼ in., the limit may be placed at about 5 pounds of oil per cubic foot of furnace volume per hour; and with forced draft equal to five inches of water, at about 15 pounds of oil per cubic foot of furnace volume per hour, assuming the oil to contain about 19,000 B.T.U. per pound. At any rate, these figures are a little better than anything I know of having been produced as yet.

It has for some years been customary in torpedo boat destroyers to use burners which will individually handle upwards of 500 pounds of oil per hour, where high capacity under forced draft is mandatory and where maximum economy is not a paramount requirement. Burners of this size have been satisfactory for this service.

A few years ago we fixed upon about 350 pounds of oil per burner per hour as the maximum individual burner output it was desirable to use, for the reason that the same intimate mixture of air with the oil spray could not be secured with the larger sizes. Thus the smaller size burners gave better efficiency. The "Tallapoosa" tests, however, show that excellent gas analyses may be obtained when delivering upwards of 600 pounds of oil per burner per hour, and Messrs. Babcock & Wilcox, Limited, of England, with their own design of air control and a modification of the Peabody burner, have recently made some very interesting tests, burning 880 pounds

of oil per burner per hour. The boiler efficiency was in this case 73.4 percent at the rate of evaporation of 16.15 pounds of water per hour per square foot of heating surface from and at 212° F. We are continuing experiments at the Bayonne plant of The Babcock & Wilcox Company, using air control similar to the "Tallapoosa" design, but of larger area, and with burner tips size No. 32 (drill number); and Mr. Stillman has recently succeeded in atomizing well above one thousand pounds of oil per burner per hour, with corresponding gas analyses showing more than 14% CO_2, with no CO.

With these figures before us, it is evident that the size of burner for future installations will be increased and the number of burners per boiler will be reduced for equivalent capacities.

With a large number of small burners, a variable load is carried successfully and easily by shutting off and lighting up burners to meet the heavier fluctuation, while the oil pressure and temperature provide very satisfactory regulation for slight variations. It is well known that the amount of oil (pounds per hour) sprayed by a mechanical atomizer varies directly as the pressure and inversely as the temperature. Below a certain "critical temperature", heating the oil increases the burner output, but ordinary working temperatures are usually above this point, so that heating the oil usually reduces the burner capacity.

The effects of pressure and temperature on burner capacity are shown in the accompanying chart, Figure 41. The size or number of the burner corresponds to the size of drill used in drilling the orifice in the tip.

Should a few large-capacity burners be installed, the flexibility to meet all load conditions decreases to some extent when using burners of the now popular fixed-orifice type. Possibly this may lead to wider use of burners of the adjustable or regulating type. A number of these are on the market, including the clever inventions of Mr. Thornycroft, one of which was used in one of our early destroyers. We have, ourselves, not found it necessary or desirable to use adjustable burners.

Mr. D. J. Irish has also proposed a burner which he calls the "High-low" type—that is, there is an adjustment which

renders the burner capable either of delivering a high capacity or a low capacity. One adjustment only, eliminates to a considerable extent the liability of faulty setting of the completely adjustable burner, which in the hands of unskilled operators is one of the objections to the latter type.

The "High-low" burner has a special field also in those cases where the plant may operate alternately at forced or natural draft. It will also be useful for port use for Naval vessels, where it is now customary to use special tips, about half the standard size.

With the quick detachable couplings now generally used, it is, on the other hand, an easy matter to substitute a large burner for a small one and vice versa.

GETTING UP STEAM.

When no steam is available for running pumps or heating the oil, several methods of procedure, depending on conditions, may be adopted for getting up steam.

1st. If steam atomizers are installed, the furnace arrangement is usually such as to permit the building of a wood fire under one of the main boilers and starting the oil pumps and burners when sufficient pressure has been raised. In this case care should be taken that the air spaces for admitting air for combustion do not get clogged up with old nails or other refuse from the wood fuel. This method is not adaptable to mechanical atomizers.

2nd. If the installation is of sufficient size, a donkey boiler will be provided which may be fired with coal or wood or by oil burned by some anti-spraying means. This is the safest and best and most practical means of getting up steam—the donkey boiler being used to run the pumps and operate the heaters while raising steam on the main boilers. In fact, some auxiliary means of obtaining steam is almost indispensable where viscous oils are used, which require heating in the tanks before they can be pumped.

3rd. A variation of the standard donkey boiler plan is the installation of a small flash boiler or coil for generating steam. These can be adapted for burning oil by the pan or

trough method, and designs of apparatus of this type are on the market.

4th. With oils sufficiently limpid to pump without heating, a hand pump delivering oil direct to one or two burners of one of the boilers may be used. This method is employed in the Navy and Coast Guard Service. Usually, oil which can be pumped can be sprayed sufficiently to get up steam slowly, or it is entirely possible to employ special emergency heaters of the open pan type to heat the oil on the way to the burners.

5th. Providing the vessel is moored near some source of compressed air, the latter may be used to run the oil pump, or live steam may be carried on board by flexible hose connections.

GAS ANALYSES.

In ordinary operation with oil fuel, the absence of all smoke is to be viewed with suspicion on account of the likelihood that this condition represents an excess of air in the furnace and consequent loss in economy. Smoke may result from other causes than lack of sufficient air, as, for instance, imperfect atomization, but it is advisable, notwithstanding, to check the admission of air to give a slight "haze" of smoke from the funnel, as all things considered, this provides the best rough-and-ready indication of the proper running conditions.

Analysis of the products of combustion is, however, the only sure method of obtaining information by which to adjust furnace conditions to give the maximum efficiency. There are several types of apparatus on the market which indicate the percentage of carbonic acid gas and thus provide very satisfactory evidence of the results being obtained in the furnace. One of these is known as the Hays apparatus, this being a convenient modification of the well known Orsat apparatus.

To some extent the operator can judge of the fire by inspection through suitable "peep holes", but personally I am disposed to distrust this evidence and to depend upon the analysis of the waste gases whenever possible. Taken by itself, the gas analysis indicates, better than any other one thing about a boiler plant, what sort of economic results are being obtained.

OIL AND COAL IN COMBINATION.

The report of the U. S. Naval Liquid Fuel Board in 1904 contained an emphatic recommendation against the use of oil and coal combined, ending as follows:

"The good of the service requires that any installation attempted should depend alone upon oil as a fuel and not on any combination with coal."

The fact that the first use of the mechanical atomizer by the U. S. Navy was for oil in combination with coal, and that today there are eight powerful battleships so equipped, does not indicate that the Board's recommendation was disregarded. On the contrary, U. S. Naval policy is committed to the rapid introduction of oil only, as a standard in all ships, and experience has demonstrated the soundness of this policy. But where coal is the main fuel, oil can be used effectively as a "booster" for obtaining more steam, or for use in port without coal, though it is recognized that the two fuels cannot both be burned in the same furnace at the same time with the best economy from either, notwithstanding some considerable experimenting with ingenious devices for burning the oil above the coal bed.

TESTS OF BOILERS USING OIL FUEL.

It is well recognized that results expressed in pounds of oil per indicated horsepower hour contain too many variables and too often include data which are unreliable to make them of value as tests of either boilers or burners. This is exemplified in the report given later by Mr. L. D. Lovekin, of the trial trip results of the U. S. S. "Melville" in which the oil per shaft horsepower, including the fuel used for operating a large number of auxiliaries, would scarcely foreshadow the excellent work done by the boilers and burners, where owing to Mr. Lovekin's supervision of the combustion, a boiler and furnace efficiency of nearly 82% was obtained.

To learn decisively what the boilers and burners are doing, it is necessary to make accurate observations of the water evaporated and oil burned and the conditions under which this is carried out. Here again errors are likely to be introduced which vitiate the results, and unless special precautions are taken by skilled engineers, the figures may be very misleading.

Ex parte tests, particularly those wherein all the conditions are not reported or where the data furnished are insufficient to permit checking up the figures by means of a heat balance, or otherwise, do not warrant recognition before scientific bodies.

I am fortunate in being able to present the results of evaporative tests of three different types of water-tube boilers (Normand, Yarrow and Babcock & Wilcox) which were tried out under the able direction of Lieutenant-Commander John J. Hyland, U. S. N., with a trained corps of assistants at the U. S. Fuel Oil Testing Plant at the Philadelphia Navy Yard in 1912 and 1913. The results of these tests are shown graphically in Figures 42, 43 and 44, which are reproduced from the charts in Commander Hyland's report.

In the tests of the Normand and Yarrow boilers, the Bureau Burner Type "Y" was used. In the tests of the Babcock & Wilcox boiler, Bureau Burners and Peabody Burners were used alternately.

Through the courtesy of Mr. Angelo Conti, of the Bureau of Steam Engineering, who cooperated with Commander Hyland in conducting some of the tests of the Babcock & Wilcox boiler, I have received the following concise report. The figures on the heat balance will be of special interest. These were prepared especially for this paper and have not been published elsewhere.

Previous to Mr. Conti's attendance at the tests, Commander Hyland ran a series of tests on the Babcock & Wilcox boiler, one of which was made at the highest possible capacity obtainable at the plant—this was limited by the air pressure, 7 in. in the closed fireroom, which was all the fan was capable of producing. During a period of three hours an average evaporation of 18.7 pounds of water into dry steam from and at 212° F. was obtained per square foot of heating surface per hour, which is believed to be the highest marine boiler capacity of authentic record. At the same time an evaporation of 15.3 pounds of water per pound of oil from and at 212° F. was secured—the oil burned per square foot of heating surface per hour being 1.23 pounds.

Babcock & Wilcox boilers of similar design to that tested at League Island are being installed in the U. S. Super-Dread-

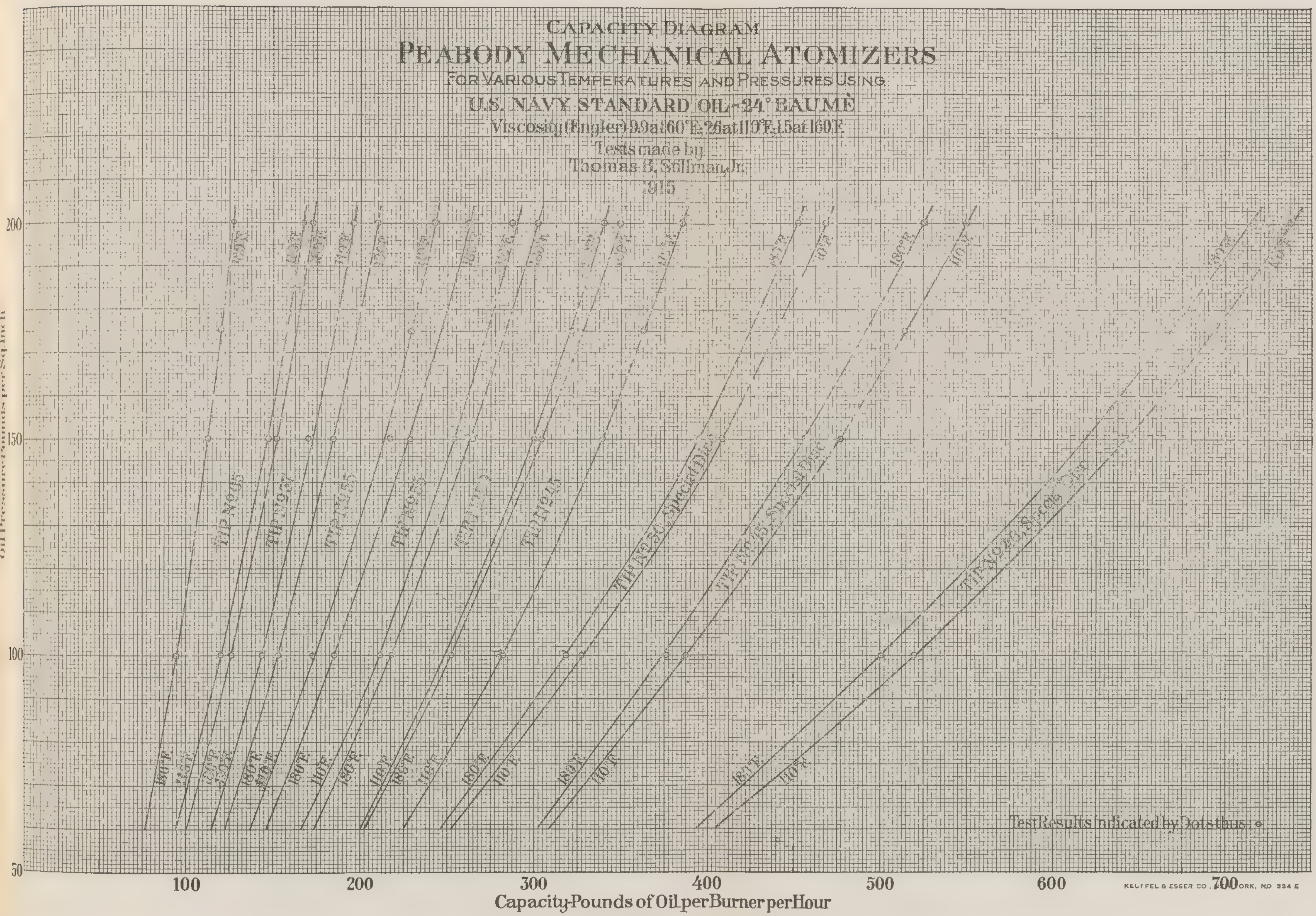

Fig. 41. Capacity Diagram. Peabody Burner.

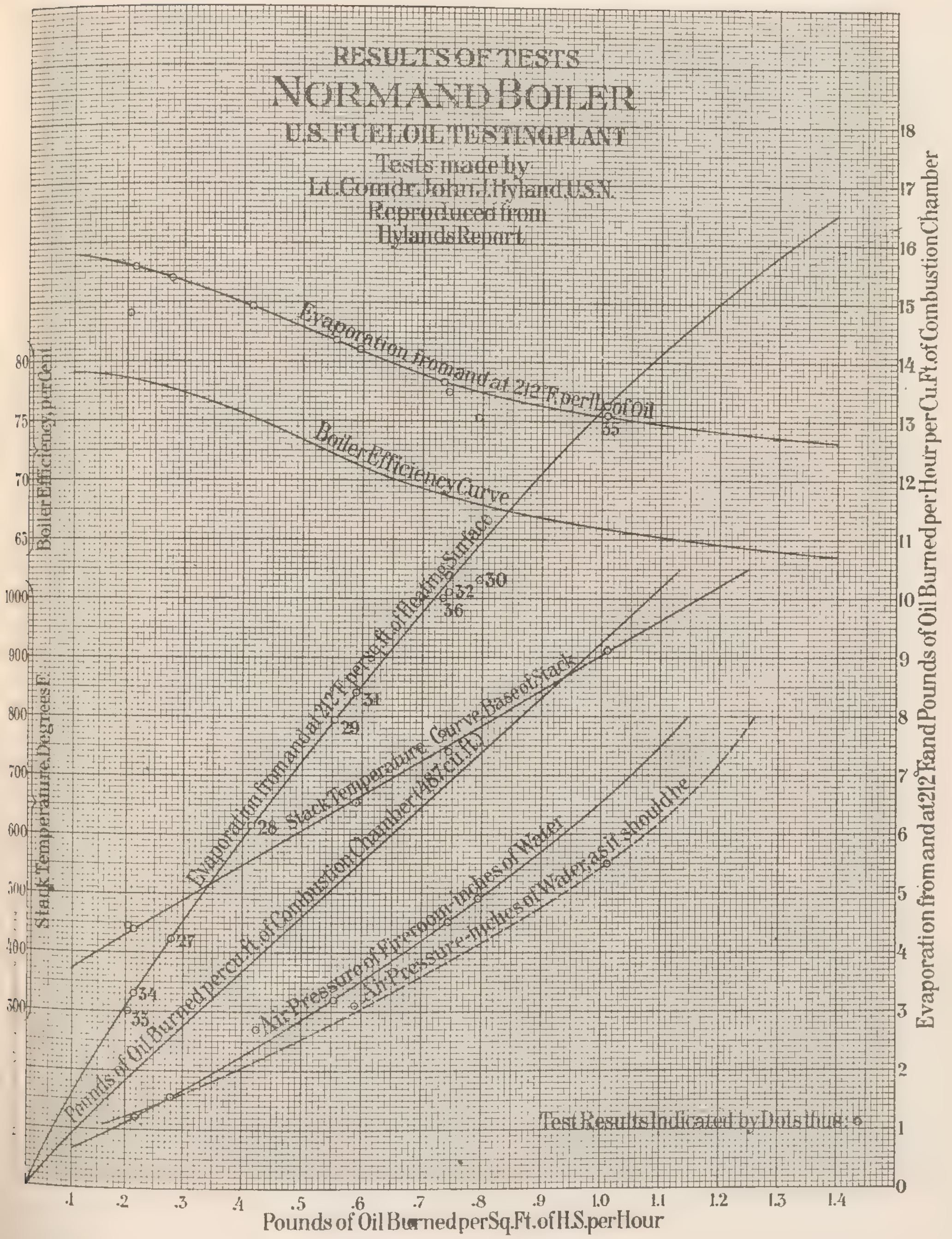

Fig. 42. Tests of Normand Boiler.

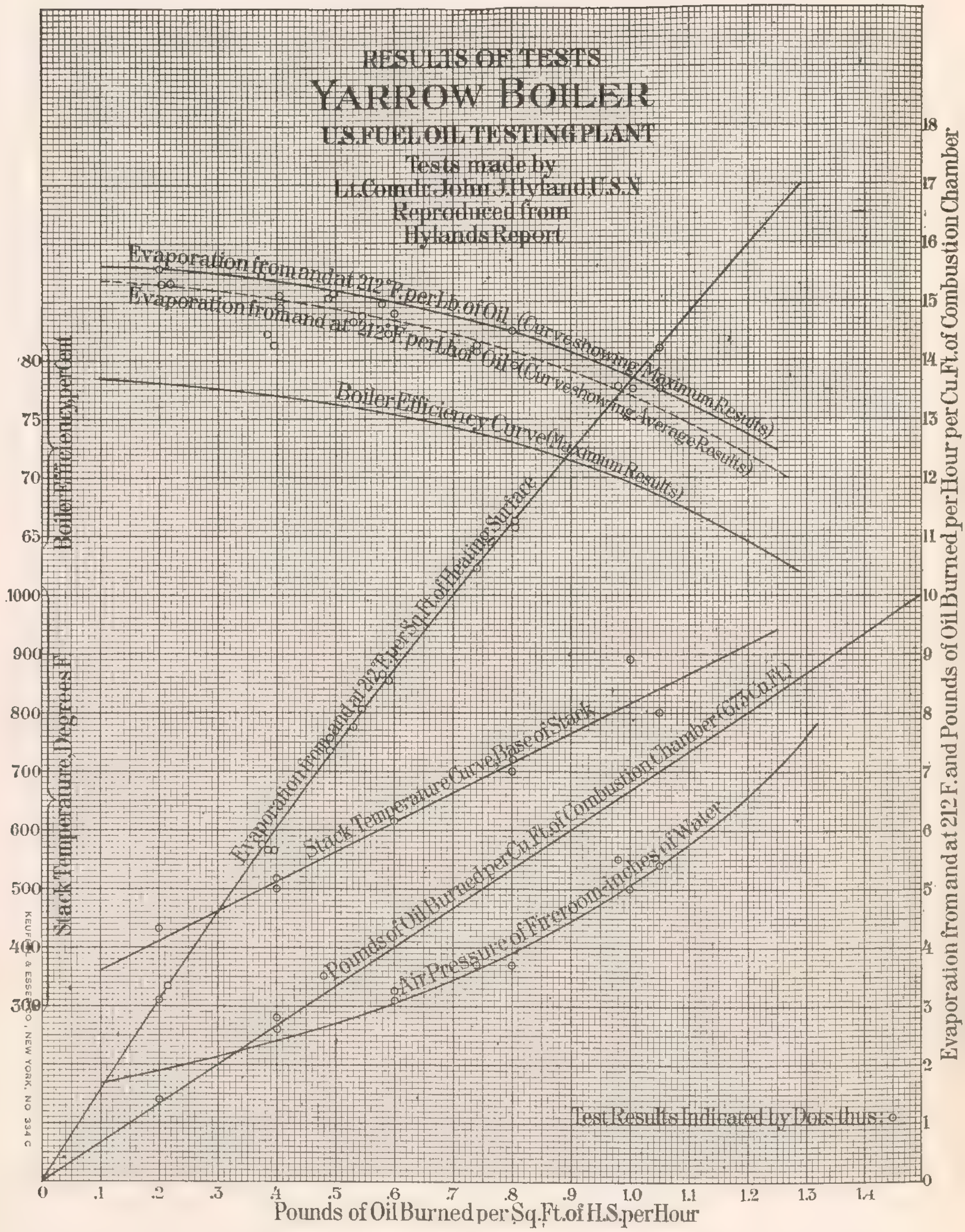

Fig. 43. Tests of Yarrow Boiler.

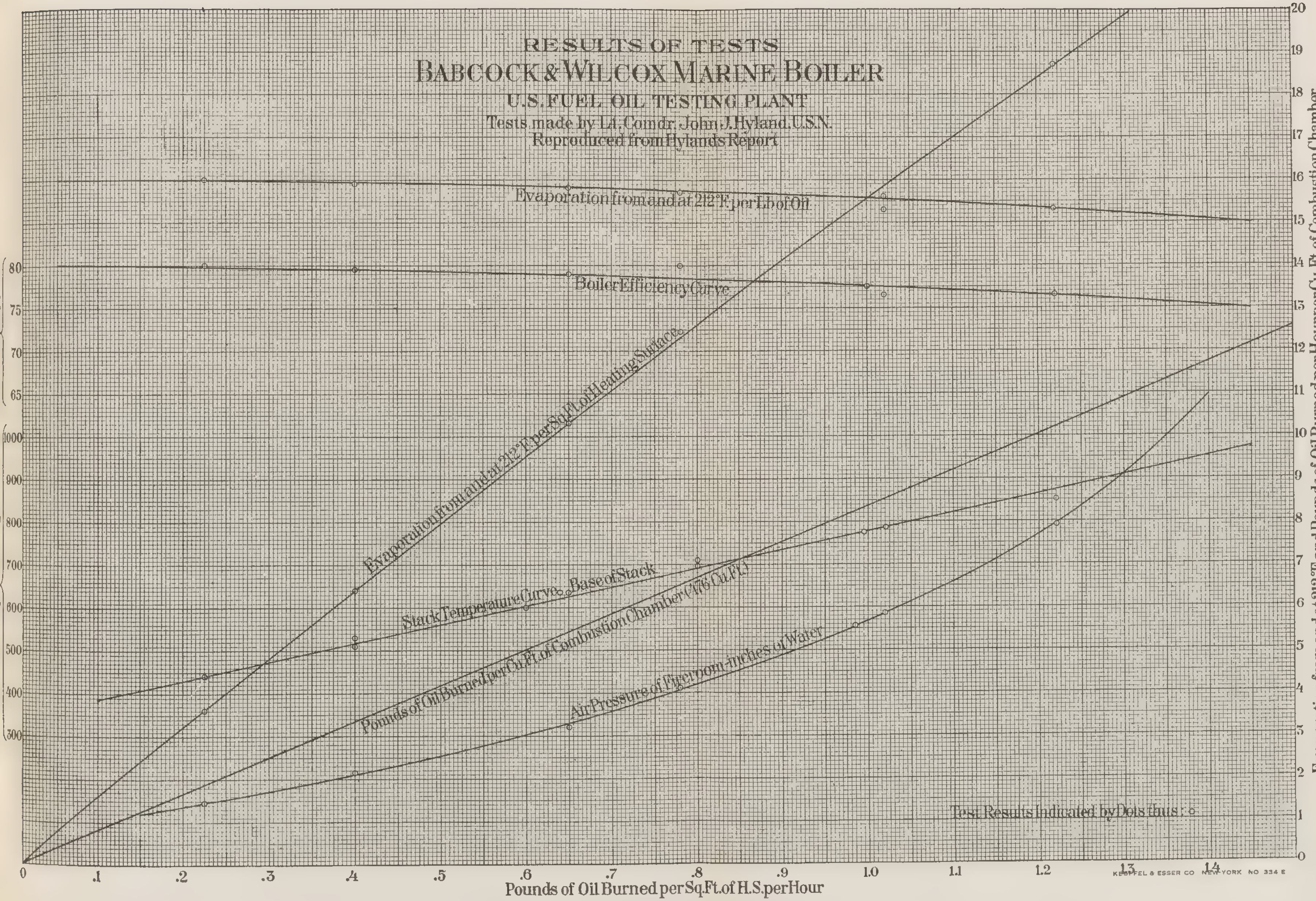

Fig. 44. Tests of Babcock & Wilcox Boiler.

Fig. 45. Babcock & Wilcox Boiler on U. S. S. ''Pennsylvania'' Fitted with Peabody Burners.

naughts "Oklahoma", "Pennsylvania", "Mississippi", "Idaho" and "Arizona"; each of these vessels will use oil exclusively. Figure 45 shows one of the boilers of the "Pennsylvania" fitted with Peabody mechanical atomizers.

Report of Tests on Experimental Oil-Burning Babcock & Wilcox Boiler at the Fuel Oil Testing Plant.

By

ANGELO CONTI.

"Following the adoption of the Babcock & Wilcox type of boiler for the battleship 'Oklahoma', burning fuel oil exclusively, a boiler of the 'Oklahoma' type was purchased for experimental purposes and thoroughly tried out at the Fuel Oil Experimental Plant, U. S. Navy Yard, Philadelphia.

"Particulars of this boiler are as follows:

No. of sections	22
No. of groups of 4—2-in. diam. tubes in each header	9
Total number of 2-in. tubes	792
Length of tubes between headers	9 ft. 0 in.
Inside diameter of steam drum	3 ft. 0 in.
Total heating surface, sq. ft.	4000
Furnace volume, cu. ft.	445

"The tests reported herein were run under the supervision of Lieutenant-Commander J. J. Hyland, Head of the Fuel Oil Testing Plant, in collaboration with the writer, who was specially detailed by the Bureau of Steam Engineering to assist in the compilation of the technical data taken by the force on duty at the Plant.

"An article by Lieutenant-Commander John J. Hyland, U. S. Navy, published in the May, 1914, number of the Journal of the American Society of Naval Engineers, profusely illustrates the type of burners and registers used in these tests and also gives a diagrammatic plan of the Testing Plant. Observations were taken throughout each test at 5 minute intervals, with the exception of chimney gas analyses, which were taken every 15 minutes by means of an Orsat apparatus. The evaporation was computed at the end of each hour and the tests continued until it was proved that the results obtained were consistent and accurate.

"In order to allow the boiler to be thoroughly heated up, the first two or three hours of each test were purposely discarded, the enclosed summary representing an average of the observations taken during the last hours of each test. Owing to the uniformity of conditions obtained, as well as the care used in eliminating observational errors, and, finally, the consistency of the results themselves, no doubt can be felt as to the accuracy of these tests, of which the following inserted table gives a summary.

Appendix to Report by Angelo Conti.

Method of Obtaining Items in Table.

Item.

1, 2. For reference.

3. Observed.

4, 5, 6. For reference.

7. Observed by spring gauge connected to steam drum, pressure practically constant.

8. From a Barrus throttling calorimeter, fitted with a closed end standard perforated nipple, connected to the main steam pipe, rising vertically from the steam drum, 18″ above stop valve.

9. From calibration after each test, taking readings with the pressure both rising and falling with no steam leaving the boiler except through the calorimeter.

10. Observed from calibrated thermometer located on the branch leading from main feed pipe to boiler.

11. Total weight of water fed to boiler corrected hourly for inequality of water level, as found from calibration of steam drum.

12, 13, 14. Observed.

15, 16. From dry and wet bulbs thermometers mounted on a perforated board placed on the suction duct of the forced draft blower to insure a good ventilation.

17. Observed.

18. Observed from a Hohmann and Maurer, nitrogen filled mercurial pyrometer calibrated at the Naval Engineering Experiment Station, U. S. Naval Academy, Annapolis, Md.

19. Observed by U-gauge.

20. From a standard Pitot Tube placed in the center of the forced draft blower discharge pipe about 5 feet from the top. This pipe is 24″ inside diameter, 15 feet high and the top is belled out and open to the fireroom. The Pitot tube is connected to an Ellison inclined gauge graduated to hundredths of an inch.

21. From observation through a large mirror adjacent to a Ringelmann chart.

22, 23, 24, 25. Orsat apparatus, drawing samples through a long perforated tube from the first pass. This location was selected on account of a leaky casing, as evidenced by the lower percentage of CO_2 shown by a Uehling continuous recording apparatus drawing from the base of the stack.

26. Computed from the formula $X = \frac{.47\ (T - t)}{L} \times 100$, in which $X =$ percentage of moisture; $T =$ calibration reading of lower thermometer (item 9); $t =$ test reading of lower thermometer (item 8); $L =$ latent heat of steam at boiler pressure.

27. Factor of evaporation $= \frac{L + (h - h_o)}{970.4}$ where L is the latent heat of vaporization, h the heat of the liquid, h_o is the number of heat units contained in the feed water entering the boiler and 970.4 represents B.T.U.'s required to convert one pound of water already heated at 212° Fahr. into steam at atmospheric pressure.
28. Item 11 ÷ item 12.
29. Item 23 × item 27.
30. Item 11 ÷ 4000 sq. ft. H. S.
31. Item 31 × item 27.
32. Item 12 ÷ 4000.
33. Item 12 ÷ 445.
34. Item 12 ÷ item 5.
35, 36. From items 15 and 16 entered in the Psychrometric Tables published by the Weather Bureau.
37. Density of aqueous vapor from Marks & Davis Steam Tables, corresponding to item 36, multiplied by item 35.
38. The weight of one cubic foot of dry air is computed from the formula:

$$P = \frac{.080723}{1 + .0020389\,(t - 32)} \times \frac{b - .378\,e}{29.921}$$

where t is item 15, b is the barometer pressure corrected to the static pressure of the air in the discharge pipe of the forced draft blower, expressed in inches of mercury; and e is the pressure due to the vapor in the air also in inches of mercury. Item 37 is added to P.
39. The velocity of the air at the center of the blower discharge pipe is computed from the formula

$$V = 1097 \sqrt{\frac{\text{item } 20}{\text{item } 38}} \text{ feet per minute.}$$

The average air velocity is from 8% to 10% lower than the center velocity, the reduction factor being taken from the results of tests made at the University of Wisconsin and borne out by tests made at the Naval Engineering Experiment Station (See Journal of the American Society of Naval Engineers, November, 1912, page 1143). As stated above, the discharge pipe has an internal diameter of 24″.
40. Item 39 corrected from results of leakage tests. (See note.)
41. $\frac{\text{Item } 40 \times 144}{\text{Item } 6}$
42. Item 40 ÷ Item 12.
43. Item 43 $= \frac{11.5C + 34.8\left(H - \frac{O}{8}\right) + 4.35S}{\text{Item } 38}$ cu. ft. per pound of fuel, where C, H, O and S are the percentages by weight of carbon, hydrogen, oxygen and sulphur respectively, as found from the ultimate analysis of the fuel.

44. (Item 42 $\div$ Item 43) $\times$ 100.

45. Computed from formula

$$W = \frac{4}{3}\,\frac{CO_2 + O + 700}{(CO_2 + CO)} \times C$$

where CO_2, O and CO are items 22, 23 and 24 respectively and C represents the amount of carbon, by weight, per pound of fuel as found from the ultimate analysis.

46. Computed from formula $\frac{3.03\ N}{CO_2 + CO} \times C$ where N, CO_2 and CO are items 25, 22 and 24 respectively and C represents the amount of carbon per pound of fuel, as found from the ultimate analysis.

47. Computed from formula $\frac{O}{.261N - O} \times 100$, where O and N are items 23 and 25.

Heat Balance.

48. Item 29 $\times$ 970.4.

49. Loss in B.T.U. per pound of fuel $= 10{,}120\ \frac{CO}{CO_2 + CO} \times C$, in which CO and CO_2 are percentages by volume from the flue gas analysis, and C is the proportion of carbon in the fuel as determined by ultimate analysis.

50. Item 45 $\times$ (Item 18 — Item 17) $\times$ .246 $\times$ C

The mean specific heat of dry chimney gases is approximately taken as .246 and C is the proportion of carbon in a pound of fuel, as determined by the ultimate analysis.

51-a. Loss in B.T.U.'s per pound of fuel $= 9H\,(H_T - h_t)$ where $H =$ weight of hydrogen contained in one pound of fuel from ultimate analysis.

$H_T =$ total heat per pound of steam at stack temperature.

$h_t =$ heat per pound of water at fireroom temperature.

51-b. Loss in B.T.U.'s per pound of fuel $= W(H_T - h_o)$ where $W =$ weight of water contained in one pound of fuel.

$H_T =$ total heat per pound of steam at stack temperature.

$h_o =$ heat per pound of water at the temperature of the oil (Item 14).

51-c. Loss in B.T.U.'s per pound of fuel $= \frac{\text{Item 46}}{\text{Item 38}}$ Item 37 $(\mathrm{H}_T - h_t)$ where

$H_T =$ Total heat per pound of steam at stack temperature.

$h_t =$ Heat per pound of water at fireroom temperature.

52. By difference.

53. From ultimate analysis of fuel, as follows:

Kind of oil	Texas	Carbon	86.00
Gravity, °Baumé	26	Hydrogen	12.70
Flash Point, °Fahr.	222	Nitrogen	.19
B. T. U.'s per pound	19,525	Sulphur	.30
		Water and sediment	Traces

Note. In order to determine the net amount of air supplied to the burners, the output of the forced draft blower was corrected by the air leakage through the boiler casing, and a special test was run for this purpose.

Both the experimental Normand and Yarrow boilers were made air tight by means of plate covers bolted on top of their stacks, while the openings of the air registers in the furnace front of the B. & W. boiler were closed tight with canvas, held on with battens. The stack cover of the B. & W. boiler was removed and the damper opened. The fireroom was closed tight and, as no steam was available, the forced draft blower was run with compressed air, its speed being regulated so as to vary the fireroom pressure from one inch of water up to nearly six inches, which was the maximum that could be obtained with pressure of compressed air at 85 to 90 lbs.

The blower output was measured as on evaporative tests by means of a Pitot tube, and obviously represents the leakage through the fireroom and the boiler casing.

It must be noted that on the leakage test the boiler was cold, which probably accounts for some of the discrepancy between the amount of air thus measured and the amount found from the chimney gas analysis. Considering, however, the number of factors involved in the computation of items 44 and 47, there exists a fair agreement between these two widely differing methods.

Official Four-Hour Ten-Knot Run of the U. S. Torpedo Destroyer Tender "Melville", July 18, 1915.*

Average R.P.M.	Speed	S.H.P.	Lbs. of Oil Per Hour	Lbs. of Water Per Hour	Water Evaporated Per Lb. of Oil	Oil per Sq. Ft. of H. S.
70.25	10.15	1275	2564	37,200	14.52	.7

The oil weighed 7.24 lbs. per gallon. The temperature of the feed water varied from 140° to 160° Fahrenheit. The B. T. U.'s in the oil were about 19,000; so that, by taking the evaporation—which was 14.52—and multiplying the same by the factor 1.103 (which allows for a reasonable

* From a letter by Mr. Luther D. Lovekin, Chief Engineer of the New York Shipbuilding Co., to the builders of the boilers, The Babcock & Wilcox Co., in which occurs the statement "During a four-hour continuous speed trial of the U. S. Destroyer Tender 'Melville' we obtained results in oil burning that so far as my knowledge is concerned have never been equalled."

TESTS OF EXPERIMENTAL OIL-BURNING BABCOCK & WILCOX BOILERS.

AT

FUEL OIL TESTING PLANT, U. S. NAVY YARD, PHILADELPHIA, PA.

1	Test No.	93	94	95	96	97	98	99
2	Date, 1913	July 16	July 16	July 17	July 17	July 23	July 24	July 25
3	Barometer	30.12	30.035	30.01	29.96	30.085	29.855	30.035
4	Length of test averaged, hours	2	3	3	3	3	4	3
5	No. of burners used	3	5	8	10	8	10	13
6	Aggregate opening of air registers, sq. ins.	77.1	128.5	205.6	270	205.6	270	334
	Steam Observations—							
7	Steam pressure, lbs. gauge	300	300	300	300	300	300	302
8	Calorimeter, lower therm. °Fahr.	310	309	286.2	267.3	303.1	292.3	272.7
9	Calorimeter, normal reading °Fahr.	312	312	312	312	309	309	309
10	Feed temperature at boiler °Fahr.	199	200.6	201.3	200.6	200.2	200.7	200.6
11	Water actually evaporated, lbs. per hour	13,052	23,644	37,504	48,216	36,638	47,662	60,325
	Oil Observations—							
12	Oil burned, lbs. per hour	871	1,578	2,532	3,192	2,486	3,182	4,005
13	Oil pressure at burners, lbs. gauge	191	218	196	207	188	194	193
14	Oil temper. at burners, °Fahr.	180	180	180	180	180	180	181
	Air Observations—							
15	Dry bulb °Fahr.	78.9	84.1	78.8	79.8	87.2	86.0	80.35
16	Wet bulb °Fahr.	65.3	67.5	67.6	68.4	72	73	64.5
17	Fireroom temper. °Fahr.	97	99.7	94.3	96.6	101	98.4	96.9
18	Stack temper. °Fahr.	446	.509	620	685	649	690	720
19	Fireroom pressure, ins. of water	1.00	2.00	3.26	4.25	3.21	4.20	5.11
20	Velocity head, by Pitot Tube, ins. of water	.29	.73	1.66	2.48	1.67	2.54	3.516
21	Smoke, Ringelmann scale	0—2	0—1	0—1	0—1	0—1	0—1	0—1
	Flue Gas Analysis, from First Pass—							
22	Carbon dioxide, per cent	12.625	14.266	14.2	14.66	14.34	15.106	15.15
23	Oxygen, per cent	5.04	2.71	2.75	2.15	4.34	3.093	2.73
24	Carbon monoxide, per cent	.00	.00	.00	.00	.00	.00	.00
25	Nitrogen (by difference) per cent	82.335	83.024	83.05	83.19	81.32	81.801	82.12
	Calculated Results—							
26	Steam quality	.999	.9982	.985	.974	.9966	.9903	.9789
27	Factor of evaporation	1.0684	1.0662	1.0545	1.046	1.0652	1.0594	1.0501
28	Actual evaporation per pound of oil, lbs.	14.984	14.983	14.812	15.104	14.738	14.98	15.062
29	Equivalent evaporation per pound of oil, lbs.	16.01	15.98	15.62	15.80	15.70	15.87	15.82
30	Actual evaporation per sq. ft. of H. S.	3.263	5.911	9.376	12.054	9.159	11.915	15.081
31	Equiv. evaporation per sq. ft. of H. S.	3.49	6.30	9.89	12.61	9.76	12.62	15.84
	Oil Results—							
32	Oil burned per sq. ft. of H. S., lbs. per hour	.218	.3945	.633	.798	.6215	.795	1.001
33	Oil burned per cu. ft. of furnace, lbs. per hour	1.95	3.54	5.69	7.18	5.58	7.16	9.00
34	Oil burned per burner, lbs. per hour	290	315.6	316.5	319.2	311	318.2	308
	Air Results—							
35	Relative humidity, per cent	47.5	42.0	55.5	55.3	47.7	53.2	42
36	Dew Point °Fahr.	57.2	58.5	61.5	62.5	64.6	67.0	54.7
37	Moisture, lbs. per cu. ft.	.0007495	.000788	.0008705	.00090	.0009646	.000555	.0006928
38	Weight of air at atmospheric conditions, lbs. cu. ft.	.07375	.0729	.07385	.07375	.07265	.0725	.074
39	Forced draft blower output, cu. ft. p. m.	6,280	9,910	14,700	18,000	14,860	18,340	21,380
40	Air supplied to burners, cu. ft. p. m.	3,360	5,710	9,125	11,450	9,335	11,840	13,980
41	Velocity thro. vanes of air registers, ft. p. m.	6,280	6,400	6,400	6,110	6,540	6,320	6,030
42	Cu. ft. of air per pound of oil	231.2	217	216	215	225.2	223.2	209.6
43	Cu. ft. of air theoretically required for complete combustion of one lb. of fuel	193.3	196.5	194	194.2	197.2	197.5	193.5
44	Excess air, per cent	19.7	10.5	11.3	10.7	14.25	13.0	8.3
	Results from Dry Gases and Ultimate Analysis—							
45	Lbs. of dry gases per pound of fuel	17.156	15.263	14.645	14.878	15.23	14.49	14.44
46	Lbs. of dry air per pound of fuel	16.98	15.15	15.23	14.78	14.77	14.10	14.11
47	% excess air over amount theoretically required for complete combustion	30.66	14.3	14.53	10.95	25.72	13.92	14.62

HEAT BALANCE.

Test No.		93		94		95		96		97		98		99	
		B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent
48	Heat utilized	15,536	79.57	15,507	79.42	15,157	77.64	15,331	78.52	15,235	78.04	15,400	78.88	15,351	78.64
49	Loss by imperfect combustion	———	———	———	———	———	———	———	———	———	———	———	———	———	———
50	Loss with dry chimney gases	1,472	7.54	1,535	7.15	1,857	9.51	2,152	11.02	2,052	10.51	2,111	10.81	2,210	11.32
51-a	Loss with moisture from hydrogen in the fuel	1,366		1,396		1,463		1,495		1,471		1,496		1,514	
b	Loss with moisture in the fuel	6	7.13	6	7.28	6	7.64	6	7.80	6	7.69	6	7.77	6	7.87
c	Loss with moisture in the air	20		20		23		23		25		14		17	
52	Radiation and error	1,125	5.76	1,061	6.15	1,019	5.21	518	2.66	736	3.76	498	2.54	427	2.17
53	Total	19,525	100.00	19,525	100.00	19,525	100.00	19,525	100.00	19,525	100.00	19,525	100.00	19,525	100.00"

TESTS OF BABCOCK & WILCOX MARINE BOILER AT BAYONNE PLANT

WITH PEABODY MECHANICAL ATOMIZERS.

FORCED AND NATURAL DRAFT.

THOS. B. STILLMAN, JR.

OIL FUEL USED.

Kind of Oil	Navy standard, 24° Baumé, 19,100 to 19,300 B.T.U. p. lb.							Panuco (Interocean Oil Co.), 18° Baumé, 18,100 B.T.U. p. lb.						
Number and size of burners	4-No. 55	4-No. 55	4-No. 55	4-No. 50	4-No. 45	4-No. 45	4-No. 55	4-No. 55	4-No. 55	4-No. 50	4-No. 55	4-No. 50	4-No. 45	4-No. 45
Date, 1915	Mar. 6	Mar. 17	Mar. 17	Mar. 17	Apr. 3	Apr. 6	Apr. 6	May 6	May 10	May 11	May 11	May 12	May 14	May 17
Duration of test, hours	2	2	2	2	2	2	2	2	3	2½	2½	3	2½	3
Boiler pressure, lbs.	196	194	193	196	205	206	192	192	189	193	188	195	196	201
Temperature of feed water, °Fahr.	40	42	42	42	45	44	44	59	60	61	61	61	61	61
Moisture in steam, per cent	----------	----------	----------	----------	----------	----------	----------	0.0	0.0	0.0	0.0	16/100 of 1%	21/100 of 1%	34/100 of 1%
Factor of evaporation	1.227	1.225	1.225	1.225	1.223	1.224	1.223	1.207	1.206	1.205	1.205	1.205	1.205	1.206
Oil pressure at burners, lbs.	137	206	308	297	217	113	130	249	157	140	167	210	146	242
Oil temperature at burners, °Fahr.	174	181	190	152	180	133	151	261	269	247	270	237	240	269
Draft, boiler side of damper, in.	—0.22	—.31	—.61	—.94	—.87	—.45	—.21	—.20	—.21	—.61	—.33	—.93	—.95	—.93
Draft, top of 3rd pass, in.	—0.22	—.30	—.59	—.89	—.65	—.32	—.21	—.20	—.21	—.58	—.32	—.83	—.78	—.60
Draft, in furnace, in.	—0.13	—.15	—.26	—.21	+.57	+.55	—.14	—.12	—.13	—.30	—.19	—.24	+.42	+.36
Air pressure in closed room, in.	0.00	0.00	0.00	+.31	+3.44	+1.65	0.00	0.00	0.00	0.00	0.00	+.33	+1.70	+3.52
Temperature of waste gases, °Fahr.	428	446	509	573	725	565	412	451	428	457	438	509	572	615
Analysis of waste gases, Sample taken top of 3rd pass: CO_2, per cent	14.90	14.6	13.6	13.4	12.9	13.3	14.5	14.4	14.1	14.3	14.2	13.5	13.4	13.8
O, per cent	1.00	1.5	2.7	2.7	2.7	2.9	1.2	1.8	2.6	2.3	2.6	3.2	3.1	2.9
CO, per cent	0.08	0.0	0.0	0.0	0.2	0.0	0.0	0.14	0.05	0.06	0.07	0.0	0.0	0.01
N, per cent	84.02	83.9	83.7	83.9	84.2	83.8	84.3	83.66	83.25	83.34	83.13	83.3	83.5	83.29
Oil burned per hour: Total, lbs.	736.	782	949	1,410	2,324	1,553	630	645	660	992	818	1,360	1,814	2,359
Per burner, lbs.	184.	196.	237.	353	581	388	158	161	165	248	205	340	454	590
Per cu. ft. F. V., lbs.	3.08	3.27	3.97	5.90	9.75	6.50	2.64	2.70	2.76	4.15	3.42	5.7	7.6	9.67
Per sq. ft. H. S., lbs.	.268	.284	.344	.512	.830	.564	.229	.234	.240	.360	.297	.494	.658	.855
Water evaporated per hour into dry steam fr. and at 212 °Fahr.: Total, lbs.	11,617	12,374	14,873	22,516	34,616	24,012	10,025	9,883	10,010	14,737	12,563	20,106	26,020	33,633
Per lb. oil, lbs.	15.80	15.83	15.67	15.98	14.90	15.48	15.92	15.32	15.16	14.86	15.32	14.79	14.35	14.26
Per sq. ft. H. S., lbs.	4.22	4.50	5.40	8.18	12.57	8.72	3.64	3.59	3.64	5.35	4.56	7.30	9.45	12.21
Efficiency, boiler and furnace, per cent	80.2	80.0	79.2	80.75	75.28	78.2	80.4	82.05	81.30	79.70	82.05	79.35	77.00	76.50
Smoke, 5 represents "black"	¾—1	¾	¾	¾	¾	¾	½	½	½—¾	½	½	¼	½—¾	½—¾

HEAT BALANCES OF BAYONNE EXPERIMENTS, USING NAVY STANDARD FUEL OIL.

Date—1915.	March 6th B.T.U.	%	March 17th B.T.U.	%	March 17th B.T.U.	%	March 17th B.T.U.	%	April 3rd B.T.U.	%	April 6th B.T.U.	%	April 6th B.T.U.	%
1. Heat absorbed by boiler	15,320	80.20	15,370	80.00	15,210	79.20	15,510	80.75	14,460	75.28	15,025	78.20	15,450	80.40
2. Heat lost due to burning hydrogen	1,405	7.35	1,432	7.46	1,460	7.60	1,478	7.70	1,574	8.19	1,482	7.71	1,390	7.23
3. Heat lost in dry flue gases	1,182	6.18	1,323	6.89	1,632	8.49	1,842	9.60	2,520	13.07	1,850	9.63	1,148	5.98
4. Heat lost due to CO	46	.24	--------	--------	--------	--------	--------	--------	132	.69	--------	--------	--------	--------
5. Heat lost by radiation and unaccounted for	1,151	6.03	1,081	5.65	904	4.71	376	1.95	520	2.77	849	4.46	1,218	6.39
Total	19,104	100.00	19,206	100.00	19,206	100.00	19,206	100.00	19,206	100.00	19,206	100.00	19,206	100.00

USING PANUCO CRUDE PETROLEUM.

Date—1915.	May 6th B.T.U.	%	May 10th B.T.U.	%	May 11th B.T.U.	%	May 11th B.T.U.	%	May 12th B.T.U.	%	May 14th B.T.U.	%	May 17th B.T.U.	%
1. Heat absorbed by boiler	14,850	82.05	14,720	81.30	14,425	79.70	14,850	82.05	14,350	79.35	13,925	77.00	13,840	76.50
2. Heat lost due to burning hydrogen	1,180	6.52	1,170	6.46	1,185	6.54	1,174	6.49	1,210	6.69	1,247	6.90	1,276	7.05
3. Heat lost in dry flue gases	1,192	6.59	1,147	6.34	1,235	6.82	1,173	6.49	1,507	8.32	1,770	9.78	1,910	10.56
4. Heat lost due to CO	83	.46	30	.17	35	.20	41	.23	--------	--------	--------	--------	6	.03
5. Heat lost by radiation and unaccounted for	795	4.38	1,033	5.73	1,220	6.74	862	4.74	1,033	5.64	1,158	6.32	1,068	5.86
Total	18,100	100.00	18,100	100.00	18,100	100.00	18,100	100.00	18,100	100.00	18,100	100.00	18,100	100.00

NOTE.—Forced draft supplied both by jet in the stack and by fan discharging into closed fire-room; all readings are referred to atmosphere. Moisture in steam not determined in tests with navy oil but conditions were similar to subsequent tests when throttling calorimeter showed steam was dry.

degree of moisture) we obtained about 16 lbs. of water from and at 212° for the average during the entire four hours; the readings were taken every thirty (30) minutes. The CO_2 was 13%. The CO was zero; the oxygen—about 3% during the entire run.

The air pressure in the fireroom was never more than 3″ and occasionally dropped as low as 2½″. The fuel oil temperature was 160°; the flue gases were from 500 to 525° by electric Pyrometer. The water in the gauge glass was from 3½″ to 4″ at all times and the smoke was of light brown.

From the above results it will be seen that we obtained a boiler efficiency of about 81.7%, which is, in my opinion, most remarkable. Further than this, there were several periods when we were evaporating 15.18 lbs. of water per pound of oil from a feed temperature of 160° into steam of 250 lbs. per square inch; and, had the trial continued for a longer period, I am positive that we could have averaged 15 lbs. of water per pound of oil for another four hours.

The above trials were made with one of the two Babcock & Wilcox Boilers furnished for this vessel, and which were fitted with the Schutte & Koerting Oil Burning Outfit complete. There were ten (10) burners in each boiler, and each burner was surrounded by an adjustable air register of the regular Koerting type; a full view of which can be had from the accompanying drawings. (See Fig. 34A.)

Prior to running these tests, we had just completed a trial of 48 hours' continuous speed at 15 knots, with both boilers in operation. The earlier part of the trial, or for about 12 hours' run, appeared very unsatisfactory, as our average water evaporated per pound of oil fell in the neighborhood of 13 lbs. I had based my calculations on an average of 14 lbs. of water from feed temperature of 200° into steam at 250 lbs. pressure, and the results were falling far short of my expectations. After making several comparative sheets hourly, in which the basis of comparison was the boiler tested at the League Island Navy Yard, I felt convinced that the principal difficulty that we were encountering was that of unclean surfaces. We, therefore, proceeded to clean the surfaces, as well as could be under operation, and we immediately began to see a great improvement in the evaporation, the next 36 hours showing an evaporation of from 13½ to 14 lbs. of water per pound of oil. This convinced me of the fact that the boilers were not clean, and upon the completion of the 48-hour run, the sides of the boiler were opened up and the boiler tubes thoroughly cleaned, after which we started on our four-hour run at ten knots speed and obtained the results hereinbefore referred to.

It might be well to mention the fact that we had installed on this vessel a Hays Continuous CO_2 Recorder, which enabled us to keep track of the CO_2 at all times. We also took several snatch samples of gas for analysis in order to check the continuous recorder and at all times we found the readings to be consistent. Furthermore, I might state that,

without the use of some such apparatus as this, it would have been impossible for us to have burned the oil in such a satisfactory and economical manner.

The above trials prove, in a great measure, the value of the oil burning experiment station which was erected by our United States Navy Department at the Philadelphia Navy Yard; for here, as is well known, have been set up and fully tested out three distinct types of boilers:—One being the Yarrow type; one the Normand type, and the other, a Babcock & Wilcox Boiler, almost identical to one of the units installed on the "Melville." Each of these boilers was fully tested out under varying conditions and curves plotted showing their characteristics at various rates of oil burning and with various grades of oil; and, had it not been for the test on this particular boiler, it would have been a most difficult as well as a most costly experiment to the ship building company to determine at just what point the maximum boiler efficiency was. But, being provided with these data by the United States Navy Department, and knowing that these tests were conducted by disinterested parties, gave us every confidence in the results and we, therefore, looked forward to being able to reproduce them within certain practicable limits. Had it not been for these tests, one might have expected two boilers in operation on the ten-knot run of the "Melville" to give more satisfactory results than one boiler did; but, knowing from the start what the maximum efficiency of this boiler was when 0.8 lbs. of oil per square foot of heating surface was being used, we, naturally, aimed to keep very close to this point.

I think it is only fair to give the United States Navy Department great credit for the way in which they have taken up the question of oil burning, and to assure them that the great expenditure necessary to carry out these experiments has been fully justified.

Another feature of the "Melville's" trial that is worthy of the greatest consideration, and to which I take great pleasure in calling your attention is the Cochrane Precision Meter with storage chamber, this vessel being the first to which this appliance was ever fitted.

This apparatus, as installed on the "Melville", is shown in Fig. 46.

The volumetric method is employed, consisting of filling a chamber of known capacity to a fixed level measured in a neck of small cross section where considerable variation in level would cause only a slight error. A light, easily moved pilot valve is actuated by floats at the measuring level of each of the two measuring tanks. This pilot valve admits steam to suitable cylinders which automatically operate the filling and emptying valves which are of the Cochrane rotary self-cleaning type. The apparatus is so designed that the valves cannot rotate until the compartment in question is either completely full or completely empty as the case may be, regardless of the rate at which water is being passed through the apparatus.

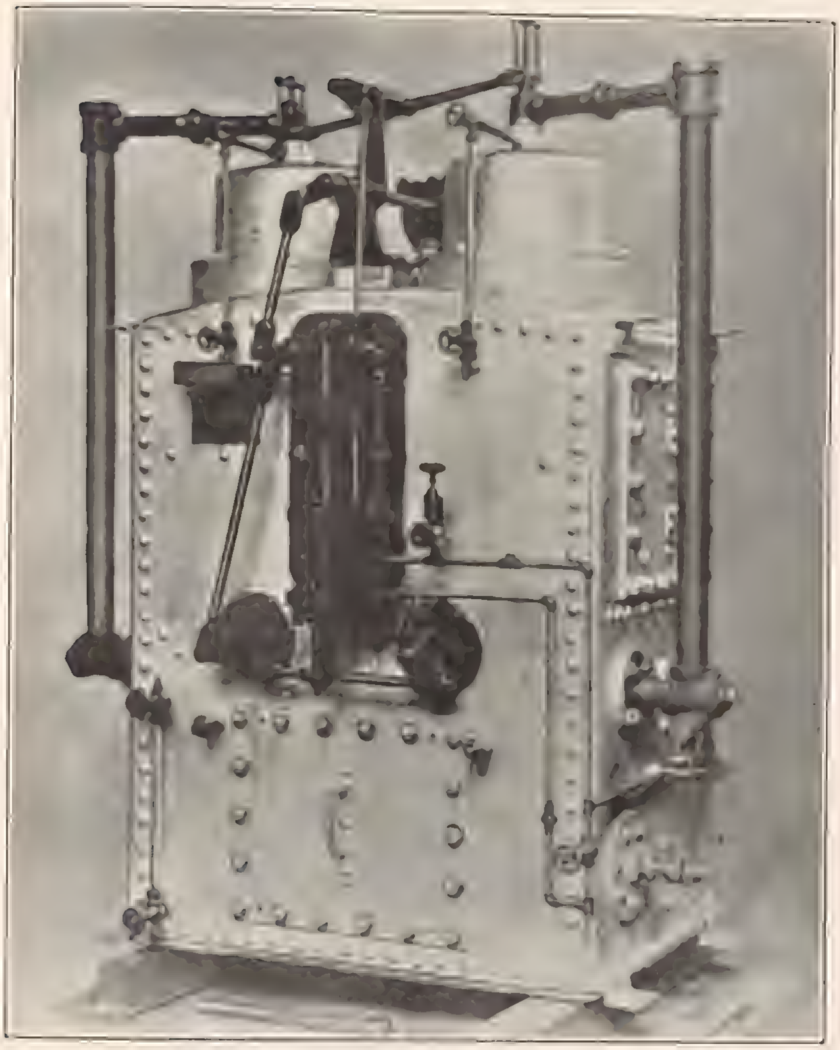

Fig. 46. Cochrane Precision Meter.

The lower storage tank is used for storing the measured water. The meter is fitted with a counter and clock-driven timing mechanism, so that the number of times the compartments have been filled and emptied in a specified time are recorded. These meters are automatic in their operation and require no attention whatsoever from anyone. They worked continuously during our entire trial trip without a hitch of any character. Their accuracy is indisputable,—calibration tests proving them to be accurate within a fraction of 1%. Without a meter of such re-

liability, one might cast grave doubts as to the results of our tests, but we feel that they are conclusive.

Extracts from Report of Official Trials U. S. Torpedo Boat Destroyer "Wadsworth", June 21, 1915.

		Full Power
Speed, knots	16.004	30.673
Total Shaft H.P.	1436	16100
Water (all purposes) per S.H.P., lbs. per hour	22.723	12.436
Oil per S.H.P., lbs. per hour	1.546	.958
Oil per Burner, lbs. per hour	395	422
Mean Air Pressure, inches	2.55	6.01
Actual Evaporation Water per Lb. of oil, lbs.	14.694	12.982
Steam Pressure at Boilers, lbs. per sq. in.	150	250.1
Feed Temperature, °F.	230.25	186.25
Boilers in Use	1	4

Fuel Oil:—

Specific Gravity = .8726
B. T. U. per Lb. = 19658.5

Description of Propelling Machinery:

There are four water tube boilers of the Normand return-flame type, having a total heating surface of 21,500 sq. ft. The ratio of heating surface to furnace volume is 10.34. Each boiler has twelve burners of one of the Bureau of S. E. patterns but only nine in each boiler were in use on the full-power official trial.

There are two independent shafts each driven by one high pressure and one low pressure Parsons turbine running at high speed, reduced by mechanical gearing to about 450 revolutions on main shaft at full power.

The gears are single helical arranged so that the greater part of the propeller thrust is balanced by the axial steam thrust of the turbines acting through the gears. A small thrust bearing is provided on the main shaft, forward of the gearing, to take the unbalanced portion of the thrust.

The vessel was built by the Bath Iron Works and trials run by them under the direction of the U. S. Navy Trial Board.

"Tallapoosa" Tests.

Previous to the installation of oil burners to operate under low natural draft conditions on the U. S. Coast Guard Cutter "Tallapoosa", The Babcock & Wilcox Company made some evaporative tests at their Bayonne plant on a Babcock & Wilcox marine boiler fitted up for experimental purposes. The tests were made by Mr. Thomas B. Stillman, Jr., and while

they were not intended for publication, every effort was made to secure correct data and the heat balance indicates a satisfactory degree of accuracy.

The oil burners and air control are shown in Figure 47 as later installed on one of the boilers of the "Tallapoosa". (See also Fig. 33.)

While primarily made to observe results with low natural draft, a jet in the stack and the air-tight house in which the boiler was installed, fitted with forced draft on the closed fireroom principle, permitted tests being made also under conditions of forced air pressures approximately equal to 4 in. of water.

The Panuco oil used in the second series of tests was furnished without charge by the Interocean Oil Company, and Dr. Leonard Waldo and Mr. C. K. McFadden of this company were present during many of these runs.

The high oil pressure carried in some of the tests was for convenience only, to avoid changing the size of burner. Attention is called to the gas analyses, which approach those secured by Commander Hyland in his tests of the B. & W. boiler.

A GLANCE BACKWARD.

The last ten years have been marked not only by wide extension in the use of oil fuel for marine purposes but by the introduction into the market of heavy viscous oils that require heating for use at the burners and for handling by means of pumps through the necessary pipe lines. The matter of viscosity of liquid fuel has become quite as important, therefore, as flash point and heat value, and is being recognized as a salient feature of oil specifications.

The past decade has also witnessed the general introduction of mechanical atomizers for deep sea service—and the designs of this apparatus have increased in number and excellence.

Experiment along the line of boiler development has, thanks to oil fuel, taken a great step forward, particularly in the matter of high capacity under forced-draft conditions, and results have been obtained which heretofore have only been

Fig. 47. Peabody Burners and Air Control Fitted to Babcock & Wilcox Boiler, U. S. C. G. Cutter "Tallapoosa".

equalled in locomotive boilers, using coal fuel burned under the very high draft pressures produced by the exhaust from the cylinders passing through a jet in the funnel. Unlike locomotive practice, however, the exceedingly high capacities obtained in marine water-tube boilers with oil fuel have been accompanied by excellent efficiency.

The introduction on the market of heavy viscous oils, the increasing use of the mechanical atomizer for sea service and advance in obtaining high boiler capacity and high corresponding efficiency seem to be the most striking features of recent developments in oil burning.

TREND OF DEVELOPMENT IN IMMEDIATE FUTURE.

It requires no prophetic vision to foresee the continued increase in the use of heavier oils. Barring such liquid fuel as gas-house tar, which, while heavier than water, is very fluid and not in the same class with viscous oils, the heaviest oil I know of being burned is 10° Baumé, or the density of water. If it should please the oil producers to put still heavier residuums on the market, these oils can and will be burned successfully. Let us hope that the flash point will be very high.

The "man of mystery", who flourished in the days of Spindle-top, with his superior oil burner with "patent insides" is no longer in evidence and it is believed that the tendency toward simplicity in oil-burning apparatus will continue—which is not to say that we know it all nor that new problems may not be met with, and, judging the future by the past, be successfully solved.

With oil as fuel, it is perhaps inevitable that boilers will be forced to still higher capacities to meet new needs—such, for example, as will be met in the steam-driven submersible war vessels. I think, too, that this matter of higher capacities, with other reasons, will be a strong influence in the ultimate use of water-tube boilers in the merchant marine to the exclusion of the enormously heavy Scotch boiler. For some years the latter type has been omitted from the battle fleet, the water-tube boiler only being used, and the same considerations that led to its adoption there (less weight, higher capacity, higher economy, greater safety and less cost of maintenance), must

eventually bring the water-tube boiler of the better type into its own.

Finally, as already intimated, there is likely to be a move toward larger individual burner capacity and a reduction in the number installed per boiler.

The production of oil is on too great a scale to expect anything but an increase in its use as an ideal fuel for marine purposes.

BIBLIOGRAPHY.

This part of the subject of oil burning has been exceedingly well covered in the list prepared by William B. Phillips and published with his paper on "Fuel Oil in the Southwest" in the Transactions of the American Institute of Mining Engineers in 1914. Mr. Phillips classified and added to the lists prepared by W. H. Dalton, L. V. Dalton, S. L. James and E. S. Ward, for the 1913 Edition of Sir Boverton Redwood's "Treatise on Petroleum".

LETTERS.

I am pleased to be able to present in this paper letters from a few men prominent in the production and the use of fuel oil. Captain A. F. Lucas writes:

"Liquid fuel should only be considered as a factor in the production and generation of power on an extensive scale, when an abundant and steady source of supply is assured. Such source should also be located at intervals throughout the various States so as to insure a reasonable cost of transportation to the points of consumption, as is now the case by use of extensive pipe line systems.

"The United States is therefore particularly fortunate in having within its border various oil fields through whose pipe lines this vast source of enormous economic importance is being distributed.

"The discovery of oil at Spindle-top, Texas, in 1901 proved the pioneer for the above requirements, for not only did this initial discovery of a very small acreage yield so far, over 45 million barrels of oil, but holding as it did a preponderant advantage by its location right on the seaboard, lead the way for the location of other pools since discovered on the Coastal Plain, which although also confined to a comparatively small area, helped to swell the aggregate production to an enormous figure. This oil was moreover splendidly adapted for fuel purposes. These small but exceedingly productive zones on the Coastal Plain, are,

however, totally different, geologically speaking, from the older and well known fields of Pennsylvania, West Virginia and Ohio.

"The advent of these unexpected and entirely unlooked for zones in Texas and later in Louisiana and Mexico added enormously to the wealth of these States, and, encouraged by its almost paramount success, large capital became available for exploration in widely distributed localities, not only in the United States but in every part of the World.

"In this manner the oil regions of the country assumed very important proportions as an available source of the national fuel supply. With its component by-products, this fuel for a time at least threatened to rival even our vast coal deposits.

"The discovery of these large volumes of petroleum in Texas may well be said to mark the point at which this oil production became of National importance. It may be pertinent for me therefore to state how the discovery of the pioneer gusher, now known as the Lucas Gusher, came about.

"In the Fall of 1899 I decided to try out a theory that the slightly raised elevations occasionally met on the Coast Plain of Texas, were in reality surface indications of some Geological or economic importance, similar to those I encountered in Louisiana, and which I figured may be overlaid with sulphur, salt or petroleum.

"Against the opinion of leading United States Geologists and experts from the Standard Oil Company who examined the locality at my instance, but encouraged by the scant but perceptible odor of SO_2 exuding from the surface, although entirely unaccompanied by any sign of petroleum or asphalt seepage to lend indication of a possible oil field below, I decided to drill a well with the hydraulic method and selected a location having a slight elevation from the surrounding prairie, the maximum of which did not exceed 12 feet, and of about 275 acres in extent, for my experiment. This low elevation was afterwards known as Spindle-top, a name that has led many to imagine it as a considerable hill, whereas on these level coastal plains it is hardly noticeable.

"The work was delayed by many vicissitudes incidental to pioneer work, but principally on account of having encountered in the process of drilling a heavy quicksand and pressure from below, which pressure filled my line with sand for 100 feet and more, the minute we released the counter pressure with the pump, thus getting the line stuck and impossible to proceed. This was repeated until it brought the proceeding to an acute stage of perplexity, which threatened the dissolution of my little enterprise, as indeed had occurred previously to others in the same effort, a thing that I did not know. I finally contrived a simple experiment (the counterpart of pumping feed water into a boiler, which, of course, is held back by its check valve) which really consisted of a wooden check valve proper, located in the coupling connecting two pipes of the line. This device proved at once an absolute success, which permitted me really to complete the well, and I may frankly state here that my success in the enterprise is due entirely to this little mechanism,

which is now well known in well drilling and especially where there is pressure from below as the 'Back pressure valve'. The well was finally completed or rather forcibly interrupted on January the 10th, 1901, at a depth of about 1135 feet.

"The Gusher started through a six-inch pipe, blowing skyward some 800 feet of four-inch line pipe used as rod in drilling, and carrying away the heavy over-head chocks, sheaves and cable.

"First vomiting the mud we used in drilling, then showers of rocks and fossils, then gas, and finally a steady flow of petroleum that rose to a height of 200 feet above ground, this flow continued without abatement for ten days before we succeeded in capping the well.

"The oil was of 23° B. and emerged from the well at a temperature of about 120° Fahrenheit, with a sulphur content of from 2% to 4%. During the ten days of unrestricted flow we confined by means of levees, etc., upon an area of 45 acres, about one million barrels.

"The subsequent boom and development is a matter of history, and the fanatical lengths to which some of the would-be explorers went are almost incredible. Anything in the way of a mound that might be evidence, by stretches of imagination, to indicate the presence of an underlying 'Dome' was drilled for oil, even Indian Mounds, and in one instance, a rather prominent 'ant-hill' proved the target for the eager oil boomer.

"However, my contention that the region may be underlaid with either sulphur, rock salt or petroleum was fully proven, in fact, all three being present, to wit: The cap rock at 900 feet was concretionary lime and calcite, containing from 10% to 50% sulphur. The next stratum of cavernous Dolomite with Fossils is the oil sand containing the oil, while below at about 1600 feet begins the salt dome which is pure rock salt and goes down to unknown depth.

"In my earliest explorations in Louisiana I had been fortunate to locate a number of these salt Domes, on what is now known Geologically as the salt islands, one of which I bored for the late Joe Jefferson with diamond drill to the depth of 2100 feet, 1900 feet of which was pure rock salt, and the drill stopped, still in salt.

"The Coastal Plains of Texas contain a number of Domes more prominent in size and elevation than Spindle-top, but although they have since been explored with far larger capital than I had resource to at Spindle-top, they have so far yielded no results. Science has therefore still to reveal to us the solution of additional problems in this connection before we will succeed in mastering all the mysteries of this complex type of Geology."

The following is from Mr. H. G. Wylie, Vice-President, Mexican Petroleum Company:

"Referring to yours of the 26th ult. (July, 1915), would state that I agree with you that it is dangerous to use a fuel oil, which, to reduce

its viscosity sufficiently for mechanical atomization, has to be heated beyond its flash point.

"There is an immense supply of Mexican crude oil sufficiently light in gravity to be 'topped', thereby removing its low flash point constituents, and still furnish a fuel oil residue of about 16° Be gravity. The topping process will certainly not increase the price of the resulting fuel oil. I consider that an oil heavier than 16° Be gravity is impractical for marine use, especially where the supply is carried in double bottoms."

Dr. L. Weinstein, of the Anglo-Mexican Petroleum Products Company, Limited, writes as follows:

"As to your first question regarding the relation between flash point and Engler viscosity, I am safe to say that there is no difficulty in making fuel oils from Mexican crude to comply with the American specification that the flash point should not be lower than the temperature at which the viscosity Engler equals 8. The following figures refer to various manufactured heavy fuel oils:

°B Gravity	°F Flash	at °F 8 Engler
15	218	182
14	228	193
13	242	200

"I am not in a position to say whether it will be possible to manufacture from Mexican crude by a simple topping process a fuel which complies with the above specification regarding viscosity and flash point. It looks to me as though it will not be possible to obtain oils of light gravity by topping. However, fuel oils of a gravity heavier than 14° Be. may be obtained by a simple topping process with a flash point sufficiently high to comply with the American specification. The above only supports the opinion I expressed to you that for future supplies of oil fuel we can only rely on heavy oils, as the lighter oils will be used exclusively in internal combustion engines or for refining purposes.

"Whoever contemplates replacing coal by fuel oil today for commercial or defensive purposes, must make arrangements to burn the heaviest fuel oils, as only these oils will be available in future. On our works and fleets we have experimented for years with heavy oil and we now find no difficulty in burning an oil of a gravity of 10° Be. either on our boats or in our stationary plants. We prefer using the pressure atomizing systems.

"In our refinery at Tampico we have 5 B. & W. boilers equipped with B. & W. burners and obtain an absolutely smokeless combustion notwithstanding the fact that our boilers are regularly overcharged. In order to obtain good results it is necessary to provide for a good oil heater and ample surface in the strainers. We found that the best temperature for burning the 10° Be. oil lies between 300 and 350° F.

and that the pressure should be in the neighborhood of 200 lbs. per square inch.''

Captain C. A. McAllister, Engineer-in-Chief, United States Coast Guard Service, writes as follows:

''If sufficient money were available to make the necessary changes, oil would be used as fuel on every cutter of the United States Coast Guard. As it is, the change from coal to oil is being made as rapidly as possible. Nine vessels out of forty-one are already fitted for oil. It is the ideal fuel for the work performed by the Coast Guard, as it

1. Raises steam quickly for emergencies,
2. Increases steaming radius,
3. Maintains uniform speed; no dropping off ten percent on account of cleaning fires, as with coal,
4. Makes no smoke when properly handled,
5. Is quickly put on board without dirt or fuss,
6. Cuts down fuel bills,
7. Reduces labor costs in fireroom at least a third,
8. Reduces boiler repairs, and cuts down paint bills.''

ACKNOWLEDGMENTS.

In addition to the gentlemen whose names I have mentioned in the preceding pages, I want to present my acknowledgments to Dr. W. F. Durand, Mr. A. M. Hunt, and other officials of the Congress for their courtesy and help, and also to the many friends who have given me invaluable assistance in the hurried preparation of this paper. I am particularly indebted to Admiral R. S. Griffin, Engineer-in-Chief, and to Captain C. W. Dyson, of the Bureau of Steam Engineering, both of whom have done much to promote the art of oil burning. Capt. Dyson's influence in this field has been, perhaps, second only to his famous work on screw propellers.

DISCUSSION

Mr. McFarland.

Mr. W. M. McFarland,* Mem. Am. Soc. M. E. (by letter), called attention to the author's long experience with the subject matter of the paper and to the important investigations in the development of efficient oil burning which he had carried out.

The author of the paper was one of the first, he believed, to call attention to the vital importance of correct air admission, and in conjunction with his assistants, Messrs. Irish and Stillman, there had been developed what the writer considered the best scheme of air admission to date.

*Manager, Marine Department, The Babcock & Wilcox Co., New York, N. Y.

Some five years ago, when Messrs. Peabody and Irish had brought out their air impeller, an installation came under the writer's notice where there was serious trouble with another form of oil burner, where the vibration or pulsation was so bad as to literally shake loose the furnace lining. Having been informed of the excellent results obtained with the air impeller, they secured permission to use it, with complete elimination of pulsations. Quite recently a similar case had arisen, and again it was eliminated by the adoption of the air impeller. The writer expressed the view that correct air admission is the vital point in oil burning, as there are a number of burners on the market which spray the oil satisfactorily. Mr. McFarland.

It was at the urgent request of the writer that Mr. Peabody discussed the subject of viscosity at such length. Experience has shown that this subject is not well understood, and that difficulty often arises because the fact is not appreciated that for best results the viscosity at the burners must be within certain limits.

It seemed also that it would be well to have the various viscometers discussed, so that some relation, if only a rough one, between the different readings could be understood. It is very discouraging, to one who is seeking information, to read that the viscosity must be a certain number of degrees by one viscometer, when all his experience has been with another, if there is no knowledge of the relation. The explanation of the different viscometers would seem to indicate that for ordinary users the Engler has the great advantage that it is self-standardizing, and the results are not changed if there is slight wear in the orifice.

Mr. Peabody has very properly called attention to the element of danger when using oils that require heating above the flash point. There was a time when it was claimed by some that there was an increase of efficiency by purposely heating the oil above the flash point. There is absolutely nothing in this, as shown by all reliable test records. The possible damage which might result from undiscovered leaks when the oil is heated above the flash point is so great that the writer believed no such risk should be taken. Oil fuel has so many advantages, and its use is so attractive from many points, that it would be most unfortunate to risk its receiving a bad name from an improper use.

Mr. J. R. Gordon* states that from the experience of the Union Sulphur Company it has been found indisputable, as stated in Mr. Peabody's paper, that heating fuel oil above the flash point introduces an element of danger on shipboard, and this danger ought not to be considered lightly by ship-owners, who are, in the last analysis, the ones who are responsible. Many vessels are today operating in regular service with oil in the pipe line leading to the burners, heated perhaps as high as 100 degrees or more above the flash point, and the practice is continued because the oil companies put on the market, at a lower price, oil which makes this practice necessary, and because operating and superintending Mr. Gordon.

*Traffic Manager, Union Sulphur Co., New York, N. Y.

Mr. Gordon. engineers are careless or ignorant, or have mistaken ideas about the possible dangers. The writer knows of one prominent manufacturer of oil-burning apparatus who has given the matter so little thought as to make the contention that the oil being under pressure, no gasification is possible. But what if a slight leakage in the piping occurs, and a portion of the oil is liberated? Leaks of this kind are possible, and Mr. Gordon says that he can testify to this fact from his own experience on the S. S. "Herman Frasch", of the Union Sulphur Co.

This vessel is fitted with three Scotch boilers, and in 1912 these were converted from coal burning to oil burning, Peabody mechanical atomizers being installed, with most satisfactory results. The piping was extra-heavy, welded iron pipe of the best quality, installed in the most careful and workmanlike manner, and tested under hydraulic pressure before oil was introduced.

After some months of operation, the engineer detected oil fumes in pockets in the lower parts of the fire-room, and further investigation revealed the fact that a slight leak had started at one of the flanges in the oil delivery line. This led to the making of tests of the oil, which showed it to have a low flash point; and on account of the viscosity, it required heating above this temperature in service.

Considering the continued use of this oil to be dangerous, the oil companies were appealed to for a supply of what was considered to be a "safe oil", but no assurance could be obtained that this would be furnished, except at a price which was prohibitive. Feeling that the situation called for drastic action, as the company positively refused to operate the vessel under conditions which they knew to be dangerous, the boilers were converted back to the use of coal and the use of oil was stopped.

Since that time the oil companies have apparently taken a different view of the matter, as one is now able to get a "safe" oil at a moderate price, and the Peabody burners have been put back on the "Frasch"; and the Union Sulphur Co. is now buying oil which they do not have to heat within about 30° of the flash point.

Mr. Gordon thinks that their experience shows that if owners will insist on a safe oil, the oil producers will supply it. If the owners are satisfied to take what is given them—either through ignorance or carelessness—some very serious disaster may forcibly call attention to a situation for which there is no excuse. Mr. Peabody is to be commended for bringing this matter to the attention of oil users.

Paper No. 215

THE APPLICATION OF DIESEL OR HEAVY OIL ENGINES TO MARINE PROPULSION.

By

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The Diesel engine is now so well known that a description at this time would seem superfluous. Therefore, this paper will be limited to the application of the Diesel engine to marine propulsion.

As is well known, the Diesel engine was originally developed for stationary purposes. It met with such great success that licenses were sold by the original developers, the Augsburg Company, of Germany, to a number of other firms in foreign countries. Among these may be mentioned the American Diesel Engine Company, the Nobel Company of Petrograd, and the Burmeister & Wain Company of Copenhagen. The American Company limited itself to building stationary engines. The Nobel Company was the pioneer in applying these engines to marine purposes. Long before oil engines were used on ships in other countries, the Nobels had a fleet of Diesel-engined ships in operation in Russia. The Burmeister & Wain Company has, in one sense, been very conservative. It has been very successful in applying its heavy four-cycle single-acting engines to merchant vessels, as will be shown later.

From the above brief sketch, there can be traced a direct line of descent of present-day marine Diesel engines from the original four-cycle single-acting stationary engine.

A special application of the Diesel engine to marine purposes is to be found in submarines. These vessels were at first fitted with gasoline engines. In certain instances steam has

been used. The Diesel engine had such manifest advantages for propelling submarines, that firms in several countries almost simultaneously took up its development for this purpose. In the United States, the Electric Boat Company was the first to build marine Diesel engines. These were of the four-cycle single-acting type. In England, a very similar type was built for submarines, by Vickers, Ltd. In Germany, the government inaugurated a country-wide competition. As a result of this, the Nuremberg branch of the Maschinenfabrik Augsburg-Nürnberg, A. G., developed a two-cycle single-acting engine. The Augsburg Company developed a four-cycle single-acting engine. The Krupps developed a two-cycle single-acting engine. From this development may be traced the modern two-cycle single-acting engine, which has been taken up by other builders and applied to large merchant vessels. During the past four years, interest in this engine has spread, so that in practically all the leading countries of the world there are large firms engaged in the development or manufacture of marine Diesel engines. While there is now a very great variety, when it comes to details and arrangements, all these engines may be classified as multi-cylinder, single-acting; some operating on the two-stroke and others on the four-stroke cycle. Approximately, three hundred vessels, of which over half are submarines, are fitted with these engines and running successfully.

A further development, yet in its infancy, is the double-acting two-cycle engine. Prior to the present European War, the Nuremberg Company had been working for over four years on a six-cylinder double-acting two-cycle engine of 12,000 horsepower. This engine was reported to have been completed last summer. The firm of Blohm & Voss, of Hamburg, had also built and successfully tested a pair of 1000-hp. two-cycle double-acting engines for a merchant ship. At the outbreak of the war, these engines were installed in the ship and trials were in progress.

The progress made during the past four years has been fair, but, to many enthusiasts, it has been a disappointment. Naturally, conservative engineers and firms equipped for building steam vessels at first held aloof, or took a pessimistic attitude toward this new development. The credit for such ad-

vance as has been made, therefore, belongs to the engineers who devoted their energies to the task and to the firms who risked their money. That the advance has not been more rapid is due not so much to the opposition, as it is to the over-confidence and enthusiasm of certain engine builders. To make this more clear, it may be stated in this way:

The builders of Diesel engines who were comparatively conservative and careful have equipped ships which have been a commercial success from the beginning. Those who have attempted too radical departures have produced engines, which, while not failures, had certain troubles. Troubles of this kind cannot be kept secret. Consequently, the steam engine advocates had an opportunity to point out these defects, and the introduction of the Diesel engines for marine purposes has been consequently retarded. While the foregoing remarks apply to builders of both the four-cycle and two-cycle types, it may be stated, in general terms, that so far as practical results are concerned, the four-cycle engine has been the most successful. This cannot be illustrated more clearly than by the work now in order with a certain foreign firm building four-cycle marine engines. This firm is building engines for twenty-five large merchant ships, and has its entire capacity engaged until 1918.

It is apparent that there exists, today, a certain difference of opinion as regards the merits of the two-cycle and of the four-cycle Diesel engine. At one time, not long ago, the trend appeared to be in favor of the two-cycle. Even today, the technical literature on the subject is very favorable to the two-cycle. On the other hand, the record of practical results is very favorable to the four-cycle. One way of expressing the situation is that there are more firms building two-cycle engines than four-cycle engines. At the same time, the firms building four-cycle engines seem to have met with more success and have a larger number of orders on hand. Of course, this state of affairs will not last indefinitely. In the course of time, the natural laws of evolution will make themselves manifest and we shall witness a demonstration of the survival of the fittest.

For the benefit of those who have not had occasion to investigate the subject, the following statement of relative advantages of the two types is given:

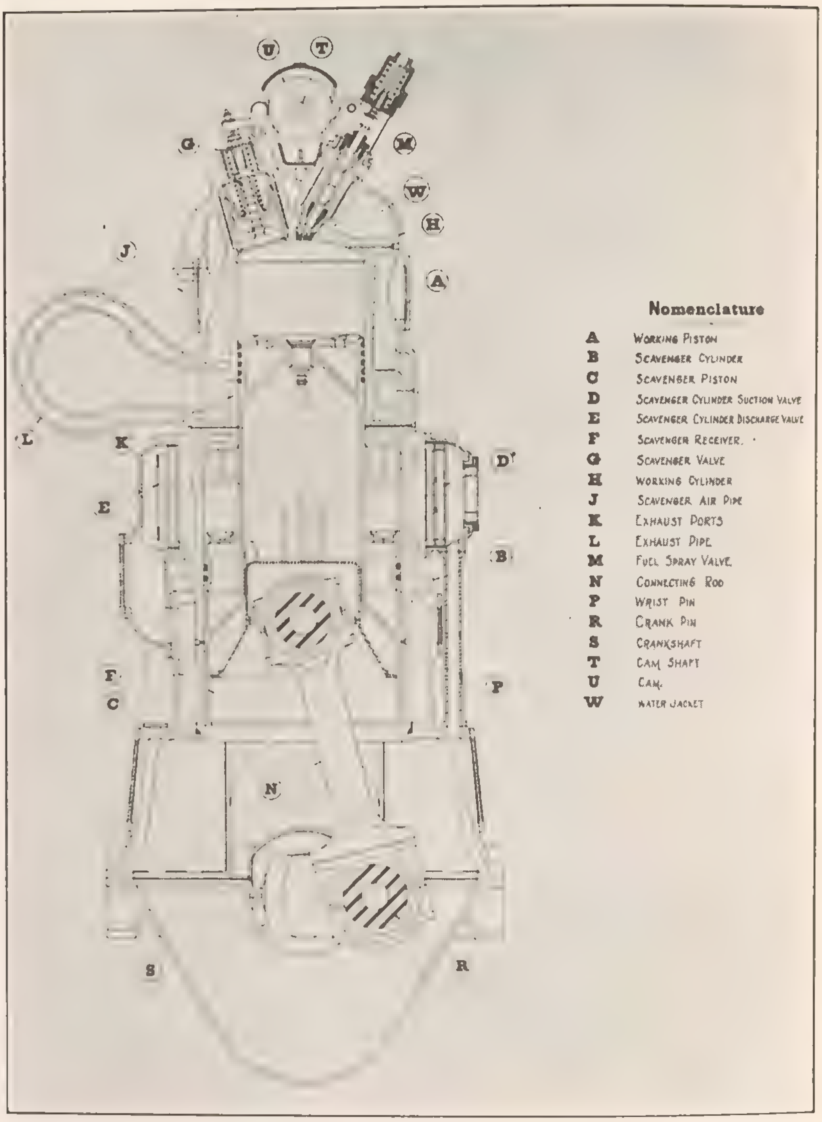

Fig. 1. Section of Two-Cycle Engine.

The two-cycle engine, superficially, has the advantage of developing double the power for a given size of cylinder. It gives one impulse each revolution, while a four-cycle engine requires two revolutions for one impulse. At first sight, it

seems to many that a two-cycle engine should therefore furnish twice the power of a four-cycle engine of the same size. This, however, is far from realization. In order to operate on the two-cycle principle, a scavenging system has to be provided. The addition of the scavenging system requires considerable space and weight and a large number of additional working parts. The net result is that after adding the scavenging system the two-cycle engine occupies nearly the same volumetric space as the four-cycle engine, and is only slightly lighter. As the scavenging system is susceptible of many kinds of design, some two-cycle engines are of less weight than others, but all are only slightly superior, as regards weight and space, as compared with four-cycle engines.

Another advantage of two-cycle engines is that, with a given number of cylinders, a more even turning moment is obtained. Consequently, a lighter flywheel can be used. In fact, with six- or eight-cylinder two-cycle engines of high speed, the flywheel can almost be dispensed with.

The reversing of a two-cycle engine is much more simple than a four-cycle. The same set of cams can be used both for the ahead and the astern motion.

Inertia forces in two-cycle engines are masked by the pressures in the cylinders, so that stresses on main bearing caps and connecting-rod bolts are very small as compared with a four-cycle engine.

The two-cycle engine has no mechanically operated exhaust valve, as the exhaust occurs through ports in the cylinder wall which are uncovered at the end of the stroke by the piston. In the four-cycle engine, the mechanically operated exhaust valve is exposed to hot gases and is the source of more or less trouble.

There are other advantages claimed by the two-cycle advocates, and it is only natural that this type should have many adherents.

The four-cycle engine has certain advantages of its own. First of all, it is, in reality, simpler. Each cylinder comes nearer to being a complete unit than in the case of the two-cycle.

As regards the number of parts, a four-cycle has not only

a less number of different parts, but also a less number of total parts. Mechanically, it is simpler than the two-cycle.

As regards heat conditions, the four-cycle engine is far superior to the two-cycle. In a cylinder of given dimensions, the four-cycle engine handles only one-half the amount of heat developed in a two-cycle of the same dimensions. Consequently, for cylinders below a certain size, the four-cycle engine does not require artificial cooling for the pistons, while this complication is an absolute necessity in two-cycle engines.

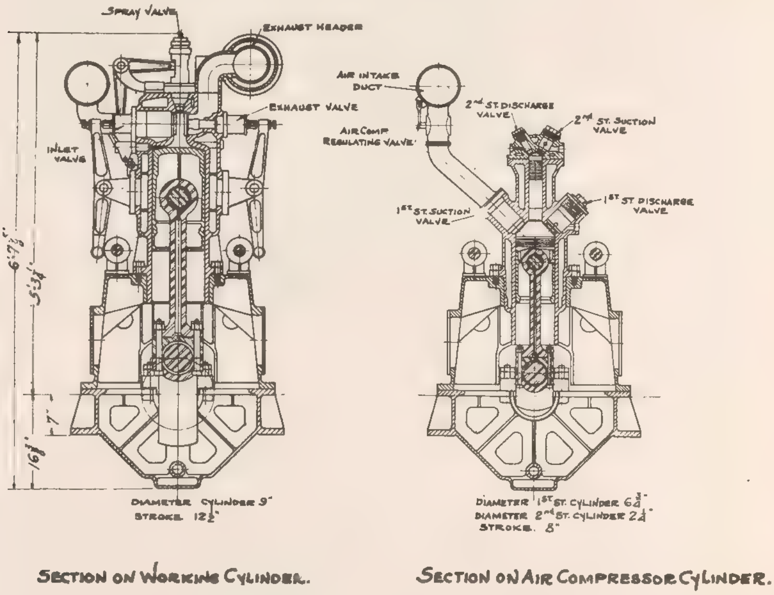

Fig. 2. Section of Four-Cycle Engine.

In the larger sizes, piston cooling is necessary in both types, but the four-cycle has the advantage of working with a much lower mean temperature, and, consequently, there is less liability to cracks due to heat conditions.

The four-cycle is more economical than the two-cycle. It is possible that, eventually, many of the disadvantages inherent in the two-cycle engine will be overcome. Certainly enough money is being spent and enough talent is engaged on the problem to achieve some very good results.

But, considering the present status of both types, it is the

opinion of the writer that, as a practical proposition, the four-cycle engine is preferable to the two-cycle.

There are certain limitations to the size of Diesel engines which may be advantageously applied to marine propulsion. The smallest engine which can well be used is in the neighborhood of one hundred horsepower. As compared with gasoline engines, the first cost of a Diesel engine of small power is such that, below this limit, the saving in cost of fuel is only sufficient to offset the interest and depreciation. As the size increases, the economy in fuel becomes of greater importance, especially on a vessel engaged in long voyages or running almost continually.

The upper limit of size is, at present, fixed by the designs and materials now in use. Up to the present, the upper limit is approximately 400 horsepower per cylinder in single-acting units; that is to say, this represents about the upper limit of engines which have been built and are in successful operation. From the point of view of the designer, it would seem possible to build successful engines of double this power in single-acting units, and of four times this power in double-acting units. In fact, experiments have been made on double-acting two-cycle engines developing 2000 horsepower per cylinder. This latter figure represents about the theoretical limit to the designer, unless some radical departure is made. Such departures are, however, possible, so that the upper limit may broadly be stated as depending upon the amount of money and energy available for development work along these lines, and is entirely a matter of the future.

Marine Diesel engines of the present day may be roughly divided into two general classes according to weight per horsepower. The light-weight class is represented by the engines used in submarines. Such engines run at a very high speed. The piston speed varies from 1000 to 1200 feet per minute. A 1000-horsepower, six-cylinder engine will, in some cases, run as high as 450 r.p.m., and will weigh approximately 40 lbs. per horsepower.

A heavy-duty slow-speed engine developing 1000 hp. at 100 r.p.m., will weigh as much as 300 lbs. per horsepower. Intermediate types are, of course, also built. For instance, the

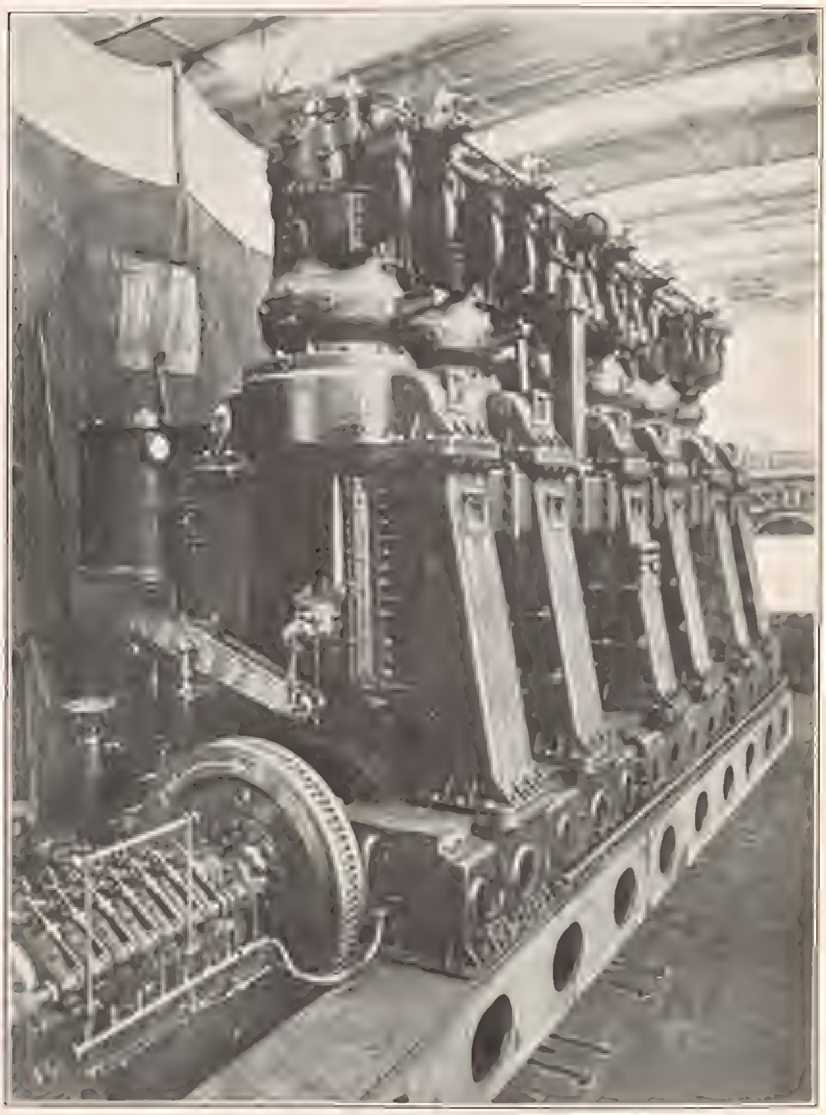

Fig. 3. Two-Cycle Engine. 1600 HP.; 130 Rev. per Min.

1000-hp. Nuremberg engine on the U. S. S. "Fulton", running at 260 r.p.m., weighs 100 pounds per horsepower.

For naval purposes, the following successful applications of Diesel engines have already been made. For submarines about 300 engines had been built previous to the European

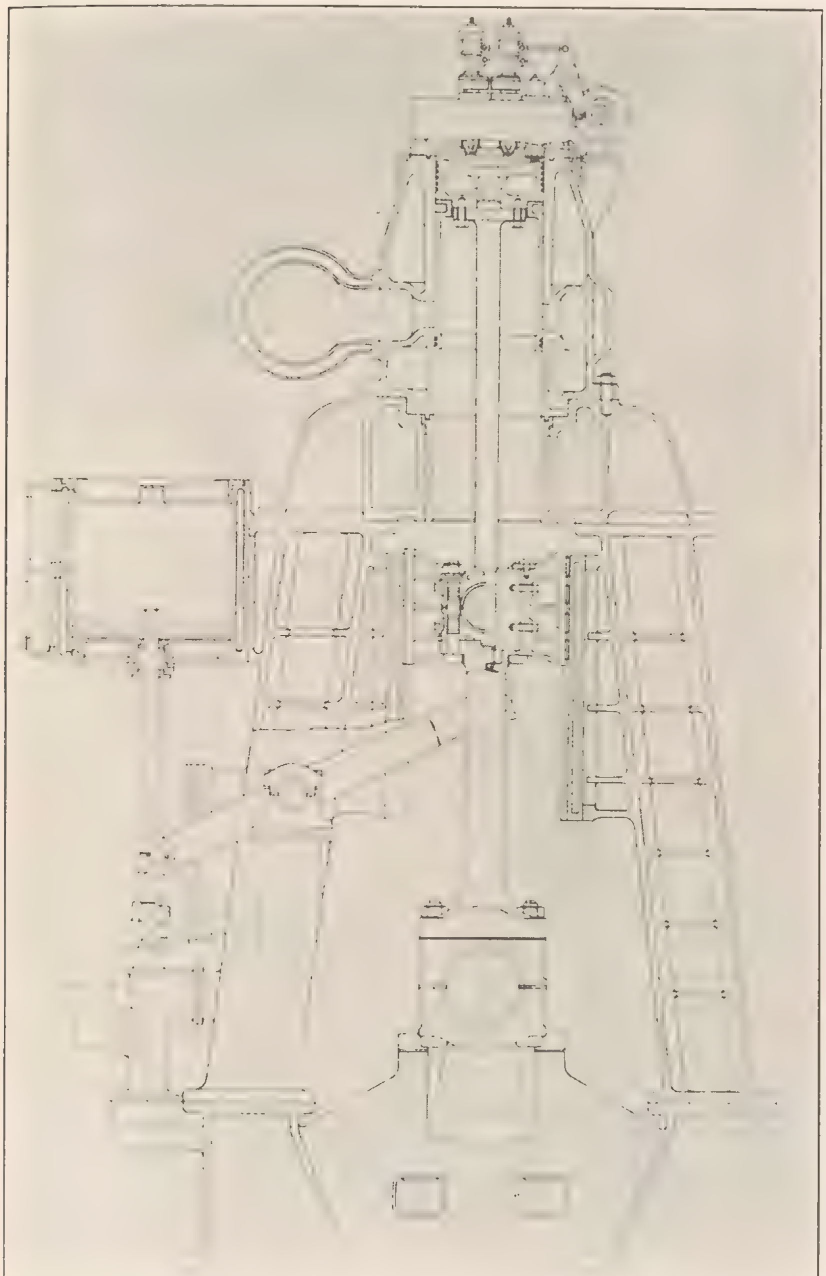

Fig. 4. Section of 1600-HP. Engine.

War. Since the war began, a large number have been built or are being built. From such information as can be obtained, it seems likely that from two to three hundred engines for this purpose alone are under construction. For this purpose, the engines range in size from 300 horsepower to 1000 horsepower. Much larger powers have been talked of, but, so far as is known, have not been actually built.

Destroyers require such enormous power (from 10,000 to 15,000 horsepower) that it is not practicable, at present, to install Diesel engines to give this output. Certain foreign countries have, however, installed both steam turbines and oil engines in destroyers. For ordinary cruising purposes, the Diesel engine is used, thereby effecting great economy in fuel and also increasing the cruising radius about 400% above what would be obtained with turbines.

For battleships, the German government intended to adopt the same scheme. By having a ship with triple screws, a Diesel engine could be used for cruising on the middle propeller, while steam turbines could be used for high-speed on wing propellers. At least two engines of approximately 12,000 hp. have been built in Germany for this purpose.

A number of battleships are also fitted with Diesel-engine electric-generator sets. These have proved very successful. The U. S. Navy has not yet made any attempt to benefit by the use of Diesel engines as auxiliaries, either for cruising or for lighting sets.

In Russia, certain gunboats propelled by Diesel engines have been in successful operation for a number of years. Austria has a cruiser equipped with a pair of 1000-hp. Nuremberg Diesel engines. Craft of this type, requiring from 500 up to 5000 horsepower, offer a large field for Diesel engines. While gunboats and cruisers can no longer be considered regular fighting units, they are still very necessary parts of any large navy. Several such vessels could have been very advantageously employed in Mexican waters not long ago, instead of keeping our expensive battleship fleet on duty there, much to its detriment in a military sense. Such minor naval craft, if fitted with Diesel engines, could be made more comfortable, more efficient, and have three to four times the cruising radius they now have, using steam.

THE YEAR 1913.

Table I. Main Diesel Machinery.

Name of Ship	Main Engines No.	Main Engines B.H.P.	Engine Design	Engine Cycle	Engineers	Cyls. per Engine	Diameter In.	Diameter m/m.	Stroke In.	Stroke m/m.	Revs. per Min.	Pumps driven by Main Engine
Suecia	2	1650	B. & W.	4-stroke	Burmeister & Wain	8	19-11/16	500	25-63/64	600	140	H.P.pump of compressed air service
Emanuel Nobel	2	2200	Werkspoor	4-stroke	Werkspoor (Amsterdam)	6	21-3/64	560	39-3/8	1000	125	2 HP fuel-feed,1 centrifugal cooling,1 fuel-tank supply,1 lubricating, and 1 bilge pumps; 3-stage lever-driven compressor
Hagen	2	2100	Krupp	2-stroke	F.Krupp Co.	6	18-45/64	475	31-1/2	800	137	2 scavenging, 2 salt-water cooling,1 fresh-water cooling, 1 sanitary and bilge, 1 lubricating oil and 1 fuel tank supply pumps; steering engine comp.
Fordonian	1	750	Carels	2-stroke	Clyde Shipbuilding & Eng'ng.Co.	4	18-1/8	460	32-1/4	820	140	2 scavenging, 2 cooling, 1 fuel tank supply, and 2 bilge pumps; 3-stage compressor.
Siam	2	2550	B. & W.	4-stroke	Burmeister & Wain	8	23-15/64	590	31-1/2	800	125	HP pump of compressed air service
Annam	2	2550	B. & W.	4-stroke	Burmeister & Wain	8	23-15/64	590	31-1/2	800	125	HP pump of compressed air service
Pedro Christoffersen	2	1650	B. & W.	4-stroke	Burmeister & Wain	8	19-11/16	500	25-63/64	660	140	HP pump of compressed air service
California	2	2300	B. & W.	4-stroke	Burmeister & Wain	8	21-17/64	540	28-3/4	730	140	HP pump of compressed air service
Wotan	1	1650	Reiherstieg-Carels	2-stroke	Reiherstieg Shipbuilding & Engine Co.	6	23-5/8	600	43-5/16	1100	90	2 scavenging,2 cooling,3 bilge, 1 sanitary, and 2 fuel tank supply pumps; main Reavell quadruplex compressor, and steering engine compressor
Loki	2	2100	Krupp	2-stroke	F. Krupp Co.	6	18-45/64	475	31-1/2	800	137	2 scavenging,2 salt-water cooling, 1 fresh-water cooling, 1 sanitary and bilge, 1 lubricating oil and 1 fuel tank supply pumps steering engine compressor
Loudon	1	1100	Werkspoor	4-stroke	Werkspoor (Amsterdam)	6	22-3/16	560	39-3/8	1000	120	1 cooling, 2 hp fuel-feed, 1 fuel-supply tank, 1 lubricating, and 2 bilge pumps; 3-stage lever-driven compressor
Fionia	2	3100	B. & W.	4-stroke	Burmeister & Wain	6	29-9/64	740	43-5/16	1100	100	Reavell quadruplex 3-stage comp.
Tynemount	2	600	Mirrlees	4-stroke	Mirrlees, Bickerton and Day	6	12	305	13-1/2	343	400	Lubricating and cooling pumps
France	2	900	Carels	2-stroke	Schneider & Co.	4	17-23/32	450	21-3/64	560	230	Scavenging pump, 3-stage compressor, lubricating oil and cooling pumps.

Table II. Auxiliary Machinery

Name of Ship	Oil Engine Sets	Steam Service	Electric Sets	Compressed Air Service
Suecia	200 bhp. Diesel dynamo and compressor in duplicate (400 bhp.), 30 bhp. Tuxham hot-bulb engine & dynamo set	Heating only	2 motor dynamos; 2 sanitary, 2 cooling, 2 lubricating, and 1 fresh-water pumps; CO_2 engine, steering engine, barring engines, emergency compressor, and winches	Whistle only
Emanuel Nobel	Deutz oil engine and dynamo	Steering engine, barring gear, ballast pump, cargo pumps and winches, boiler and condenser pumps, whistle, auxiliary compressors (l.p. & h.p.)	None	None
Hagen	275 bhp.Diesel-Reavell compressor in duplicate (550 bhp.), 23 kw. hot-bulb engine & dynamo set	Steering engine, capstan, winches, cargo pumps, 1 ballast pump, dynamo set, bunker oil pump, bilge pump, boiler and condenser pumps, and whistle	Bilge pump, ballast pump, and settling tank pump	Steering engine and whistle
Fordonian	None	Dynamo set, ballast pump, bilge pump, steering engine, winches, boiler pumps, whistle, auxiliary compressor, sanitary pump, fuel-loading pump and special cargo gear	None	None
Siam	300 bhp. Diesel dynamo and compressor in duplicate (600 bhp.), 30 bhp. Tuxham hot-bulb eng.& dynamo set	Heating only	Motor dynamo,emergency compressor,ballast pump, 2 sanitary and bilge pumps, 2 circulating pumps, 2 lubricating pumps, settling tank pump, barring gear, winches, capstan, and steering engine	Whistle only
Annam	300 bhp.Diesel dynamo and compressor in duplicate (600 bhp.),30 bhp.Tuxham hot-bulb engine & dynamo set	Heating only	Motor dynamo,emergency compressor, ballast pump, 2 sanitary and bilge pumps, 2 circulating pumps, 2 lubricating pumps, settling tank pump, barring gear, winches, capstan, and steering engine	Whistle only
Pedro Christoffersen	200 bhp.Diesel dynamo and compressor in duplicate (400 bhp.),30 bhp.Tuxham hot-bulb engine & dynamo set	Heating only	Motor dynamo; 2 sanitary, 2 cooling, 2 lubricating, and 1 fresh-water pumps; CO_2 engine, steering engine, barring gear, emergency compressor, ballast pump, and winches	Whistle only
California	180 bhp.Diesel dynamo and compressor in duplicate (360 bhp.)	Capstan and winches, emergency compressor set, boiler and condenser pumps	Steering engine; 2 sanitary, 2 cooling, 2 lubricating, and 1 fresh-water pumps; barring gear, and ballast pump	Whistle only
Wotan	160 bhp.Diesel-Reavell compressor, 60 hp. Diesel dynamo	Dynamo set, evaporator, emergency compressor set, ballast pump, reserve cooling pump, barring gear, cargo pumps, capstan and winches, whistle, steering engine, boiler and condenser pumps	Reserve cooling pump and settling tank pump	Steering engine and whistle
Loki	275 bhp. Diesel-Reavell compressor in duplicate (550 bhp.), 23 kw. hot-bulb engine and dynamo set	Steering engine, capstan, winches, cargo pumps, 1 ballast pump, dynamo set, bunker oil pump, whistle, bilge pump, boiler and condenser pumps	Bilge pump, ballast pump, and settling tank pump	Steering engine and whistle
Loudon	None	Steering engine, capstan, winches, whistle, l.p. compressor set and h.p. compressor set as stand-by, 13 kw. dynamo set and 5 kw. dynamo set, CO_2 engine, ballast and sanitary pumps, evaporator, boiler and condenser pumps	None	None
Fionia	200 bhp.Diesel dynamo set in duplicate (400 bhp.), 30 bhp. Tuxham hot-bulb engine and dynamo set	Heating only	Motor dynamo, emergency compressor, ballast pump, CO_2 engine, 2 circulating pumps, 2 lubricating pumps, 2 sanitary and bilge pumps, settling tank pump, barring gear, winches, capstan, steering engine and Reavell quadruplex 3-stage compressor	Whistle only
Tynemount	None	Steering engine, dynamo set, bilge pump, ballast pump, sanitary pump, whistle, capstan, winches, boiler, and condenser pumps	2 alternating current generators and 1 alternating current motor of 500 bhp., also 2 exciters	None
France	25 hp. paraffin engine, driving dynamo, emergency compressor, ventilating fan, and centrifugal pumps for oil and water	None	None	None

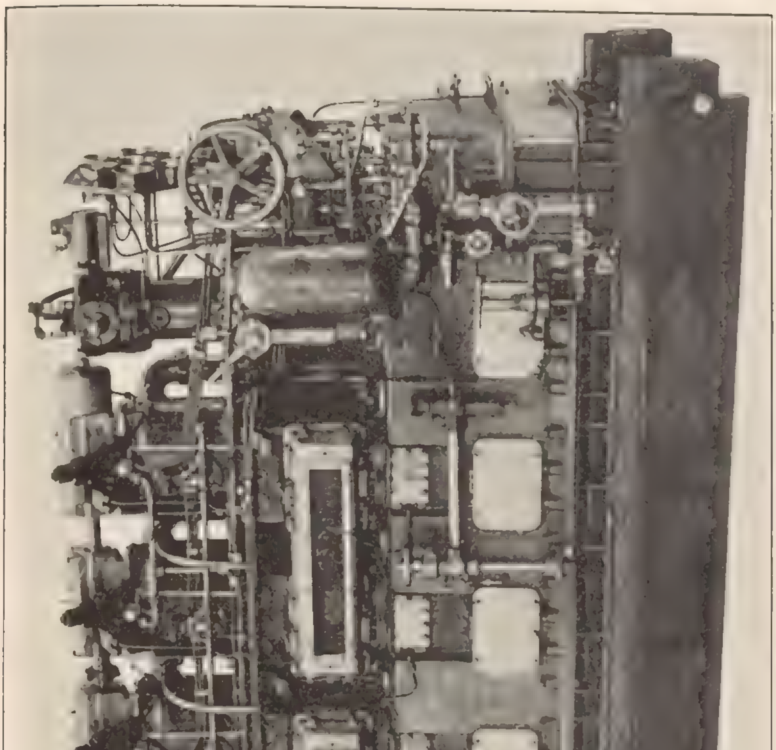

Fig. 5. Two-Cycle Engine. 450 HP.; 450 Rev. per Min.

Fleet auxiliaries, such as fuel ships, repair ships, and ammunition ships, could also be driven by Diesel engines to advantage. Some of the European countries have already made a start in this direction. The U. S. Navy is now building the fuel ship "Maumee", to be equipped with two Nuremberg two-cycle engines, developing about 2500 horsepower each. These will be about the largest slow-speed heavy-duty engines thus far attempted, and represent a bold step, as the government has had no previous experience in building engines of this type, even in smaller sizes.

For commercial purposes, engines from 50 horsepower up to 2400 horsepower are in operation. The technical press, for the past few years, has been full of descriptive articles pertaining to the principal motor-driven ships, and, consequently, no effort will be made to enter into detail descriptions here. There is reproduced, at the end of this paper, a table which was published by "Internal Combustion Engineering", showing the principal characteristics of the motor ships of 1913.

To illustrate the extent of the motor-ship industry, the following data have been collected. These data are by no means complete, but will give a fair idea of what is being done.

Figures of July 1, 1914, relative to Ludwig Nobel of Petrograd, Russia, show:

Built and building—65 ships with 106 engines and 561 working cylinders, with a total power of 50,740 b.h.p.

Reversible engines	63
Non-reversible engines	43
Four-cycle engines	75
Two-cycle engines	31

38 ships are already in operation.

15 ships to be brought out early in 1915, and the rest to follow a year later.

50 ships are warships and 15 are merchant ships.

The smallest engine is 50 hp.

The largest engine is 1500 hp.

Figures of the same date relative to Burmeister & Wain show:

Large motor ships completed	17
Motor ships on order	25

Capacity engaged until the year 1918.

The New London Ship & Engine Company, which started operations in 1910, has built practically all the marine Diesel engines produced in the United States. Although it has been in operation only a comparatively short time, its record to date is as follows:

Engines built and building	107
No. of cylinders, approximately	600
Total horsepower, approximately	40,000
Smallest engine	60 h.p.
Largest engine	1,000 h.p.

The following is a partial list of some of the large European firms, in addition to those above mentioned, who have extensively engaged in the construction of marine Diesel engines:

Vickers, Limited, England.
Mirlees, Bickerton & Day, England.
Werkspoor, The Netherlands.
Carel Freres, Belgium.
Sulzer Bros., Switzerland.
Schneider & Co., France.
Fiat Co., Italy.
Blohm & Voss, Germany.
F. Krupp Co., Germany.
Maschinenfabrik Augsburg-Nürnberg, A. G., Germany.

The above is by no means a complete list of European builders of Diesel engines, but includes such well known names as to give a fair idea of the extent of the industry, which has been steadily growing during the past five years.

Undoubtedly, the present war has retarded construction in some lines and accelerated it in others.

The one reason for going ahead with Diesel engines for marine purposes is fuel economy. For naval purposes it is not a question of money so much as a question of increased radius, and other military advantages. For this reason, we may look forward to a steady development in this form of motive power in all navies.

For commercial work, the question resolves itself simply into one of dollars and cents. Enough experience has already been obtained to show that, in certain classes of vessels on cer-

tain trade routes, the Diesel engine does pay; hence the number of ships building at the outbreak of the war.

The advantages, as applied to certain merchant vessels, are, in general: economy in fuel; increased cargo capacity; decreased engineer force; and absence of standby losses.

There has always been a difference between the European and American point of view, due to conditions. Previous to the present war, it may be stated, in general terms, that, in

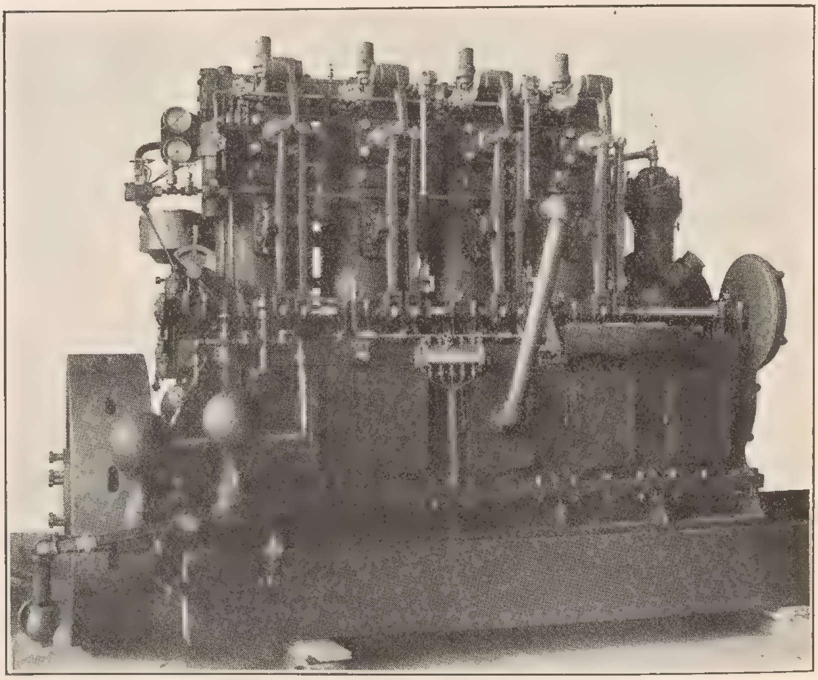

Fig. 6. Four-Cycle Engine. 240 HP.; 240 Rev. per Min.

Europe, capital was comparatively plentiful and fuel comparatively scarce. Consequently, the European shipowner considered ultimate saving, and was willing to pay a greater first cost for his propelling plant, if the operating economy would show an ultimate gain. In the United States, the shipping business has never been given much encouragement, and those who have gone into the business have had to consider first cost very seriously. Furthermore, both coal and oil are comparatively

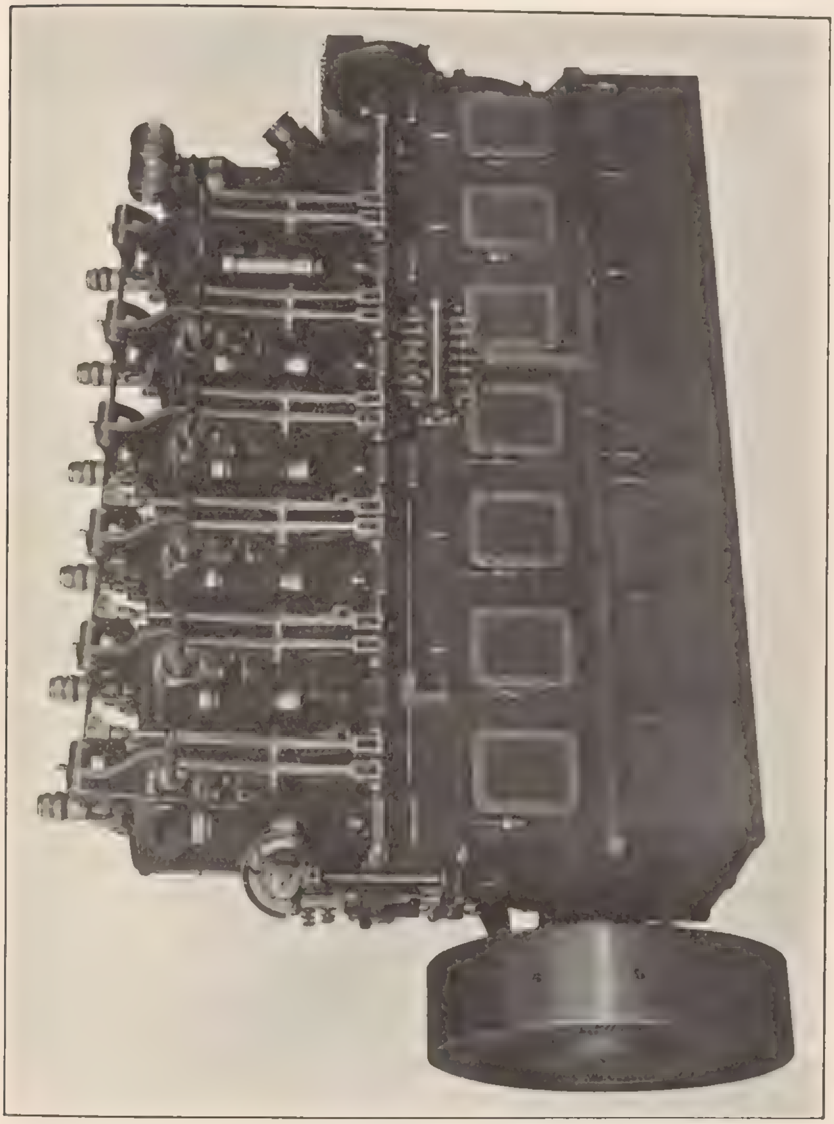

Fig. 7. Four-Cycle Engine. 180 HP.; 375 Rev. per Minute.

cheap in this country. Finally, information in regard to Diesel engines has been obtained principally from the technical descriptions of foreign vessels. It is only comparatively recently that Diesel-engined ships have visited American ports, so that first-hand information from actual observation has been scarce. A further drawback to American development has been the lack of trained operators. In the course of time, the basic advantages will be realized in the United States and the necessary trained operators will be developed. Under present circumstances, it is impossible to install a Diesel-engine plant at the same cost as a steam plant. There is a possibility that a Diesel engine may eventually be developed which will cost so little more than a steam plant, that the difference will not be worth serious consideration. When that time comes, if it ever does, we shall probably see a boom in the marine Diesel-engine business, paralleling the history of the automobile, both in Europe and America. At present, many ships intended for trade between the Atlantic and Pacific Coasts, through the Canal, are being fitted to burn oil under their boilers. To one acquainted with the operation of a Diesel engine, this seems to be almost a wicked waste. The same amount of the same fuel used in a Diesel engine would run four ships instead of one, or would carry the one ship four times as far.

There are, of course, many cases where a Diesel-engine plant would not prove as desirable as a steam plant. These cases depend upon locality and the nature of the service. It is apparent, that in a locality where coal is very cheap and oil expensive, it will be foolish to use oil. A vessel engaged, locally, on short trips could not derive the same advantage as a vessel making long voyages.

Anyone who contemplates building a new ship, or repowering an old one, should carefully investigate the matter for himself before deciding on the kind of motive power to be installed. The following brief data will be found sufficient to form a basis for estimates:

The Diesel engine, on the average, will use one-half pound of fuel per shaft horsepower hour.

The steam engine, on the average, will use two pounds of fuel per shaft horsepower hour.

The Diesel engine, as now built, will require the same number of engineers as the steam plant, but will not require the fireroom force.

The Diesel engine, at present, will require a higher type of engineer than the steam engine, and, therefore, slightly higher pay.

The Diesel engine will require more lubricating oil than the steam engine. This depends very much upon the design and type of engine. Information on this point should be obtained from the engine builders.

The average yearly deterioration of the Diesel plant will be about the same as that of the usual steam plant.

Interest on investment can be calculated, of course, upon the prices quoted.

The cost of repairs and upkeep will depend on the type of engine. No exact basis can be given, and Diesel engines have not been in operation sufficiently long to furnish a general average. When one considers the ordinary repairs in a steam plant, boilers, furnaces, condensers, and pumps, in addition to the engine proper, it seems reasonable to assume that, in the long run, a properly-built Diesel engine, adapted to the work required, should show a much smaller repair bill.

Probably the worst enemies of the marine Diesel engine, during the past few years, have been the over-enthusiastic advocates. Many have made promises they could not fulfill. Others have built and installed engines which were nothing but experiments. New firms are continually entering the field, little realizing that the design and construction of these engines are highly developed specialties. The first engines produced in this way are generally failures; and, unfortunately, the good and the bad suffer as a result. The experienced builders approach perfection only by close application, and naturally do not publish to the engineering profession all of the practical points which they develop in the course of their work. The individual or firm with small resources is taking a desperate chance when he or it plunges into this line of work. So, also, are the customers who buy the first engines turned out.

It is regretted that space will not permit going more into detail as regards this important subject. An effort has been

made to treat the subject in a very broad manner and to give an idea of the status of the Diesel engine as applied to marine propulsion today.

We have every reason to look forward to a continuation of the present development, and in the course of the next few years we may hope to see a less number of types and a greater number of engines in use.

DISCUSSION

Lieut.-Com. Shane.

Lieut.-Commander Louis Shane, U. S. N., said (by letter) that he believed the author had overlooked what would probably prove to be the greatest and perhaps the best application of Diesel engines to marine purposes. The U. S. Navy fuel ship ''Jupiter'', propelled by electric motors, was so much of a success that the Navy Department is now building the ''California'', probably the largest battleship in the world, with the same motive power. The generators, however, are steam-turbine driven. Commander Shane believed the thought of this should be enough to give the Diesel engine designer a pleasant thrill, for there appeared to be no greater field for the Diesel engine.

The upper limit of about 400 hp. per cylinder for Diesel engines is due to the difficulty in cooling the cylinder walls after they get beyond a certain thickness. This problem is easily met in the electrically-propelled ship having, instead of a few very large units, many small high-speed units, with a triple advantage: first, the high-speed engine is lighter per horsepower than the low-speed engine; second, the number of units can be regulated according to the power required, all operating engines running at approximately their rated power for any speed of the ship; third, the large cylinders with thick walls are done away with, the size of the engines being what has already been found to be successful. Engines will not be reversed, eliminating the complicated reversing gear.

In Commander Shane's opinion, the future of the marine Diesel engine lies in the electrically-propelled ship, here being a field so vast as to stagger the imagination.

Paper No. 216

THE DIESEL ENGINE APPLIED TO MARINE PURPOSES.

By

C. KLOOS

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Amsterdam, Netherlands

When speaking on this subject it is necessary to distinguish engines for naval crafts from those for mercantile marine purposes.

I presume that it is not the idea of this congress to extensively discuss the Diesel engines applied for war purposes; moreover this could not be done very profoundly as each Navy tries to keep the design of its engines secret as much as possible. Diesel engines in the Navy are nearly exclusively found in submarines. They are all high-speed, extremely compactly-built engines. In the motors for those small ships, part of the reliability and durability must be sacrificed to obtain lightness and small bulk, but, running only at great intervals, there is no objection that the dimensions should all be chosen very small even if this would soon cause great wear and tear with continued use.

Also the fact, that with eventual repairs the parts are not easily accessible is no objection to those engines, because plenty of time is always available for such repairs.

As the marine Diesel engines were used for naval purposes before they made their entrée in the mercantile marine, some of the first engines destined for the latter have experienced the drawbacks of their resemblance to the naval motors.

Concerning the beginning of the application of Diesel engines for mercantile ships, we mention that the first engines, of at least some hundreds of horsepower, were started in Russia on the river Volga and the Caspian Sea. They were destined for ships owned by the firm of Nobel Bros. in Petrograd and were partly built in their own shops in Petrograd and partly at the Kolomna

Works in Moscow and at Aktiebolaget Diesel Motorer in Stockholm.

The fact that these new marine engines were first built in Russia, whereas formerly never had the first specimen of a novel engine been produced in this country, had two reasons.

First, because there are big oil wells at the Caspian Sea, whereas other fuels are very expensive in that vicinity. This brought therefore the first stationary engines from the Maschinenfabrik Augsburg-Nürnberg at an early time to these countries.

But, that cheap oil and expensive coal do not necessarily lead to the early adoption of marine Diesel engines, is demonstrated here on the Pacific Coast of the United States, where circumstances are the same in this respect. But nevertheless, this country was not the birthplace of the marine Diesel engines, notwithstanding that the Western people were acquainted with these motors at an early stage of their development, but they thought that the best use they could make of their oil was to burn it under the boilers. The second factor was the sense for progress with the firm of Nobel Bros., who, being owners of oil fields as well as of ships and engine works, had everything in their own possession necessary for the realisation of their progressive schemes in this line.

In this way there existed in Russia several marine Diesel engines long before the rest of the world earnestly considered the manufacture of such engines. The construction, however, was mainly the same as of the standard land engines of the Maschinenfabrik Augsburg-Nürnberg, with some changes. But when observing the present-day big Diesel engines for sea-going ships, it is noticed that the valves and valve gear are copied from the original land engines, but for the rest they are different in many ways. After the engines of Nobel Bros., a few small marine Diesel engines were turned out in 1910 by Sulzer Bros., of Winterthur, and the Machinenfabrik Augsburg-Nürnberg. These engines were high-speed, box-frame engines of comparatively low power. They did not yield much satisfaction in continued service, nearing too much the style of submarine engines.

The 600-b.h.p. land engine exhibited by the Werkspoor Works of Amsterdam at the Brussels' Exposition of the year 1910 was of a general construction since followed in many big marine motors.

To make this clear I compare a cross section of the "Vulcanus" and "Fionia" engines, Figs. 2 and 3. The former is the first sea-going vessel with Werkspoor engine; the "Fionia" is one of many successful ships built and engined by Messrs. Bur-

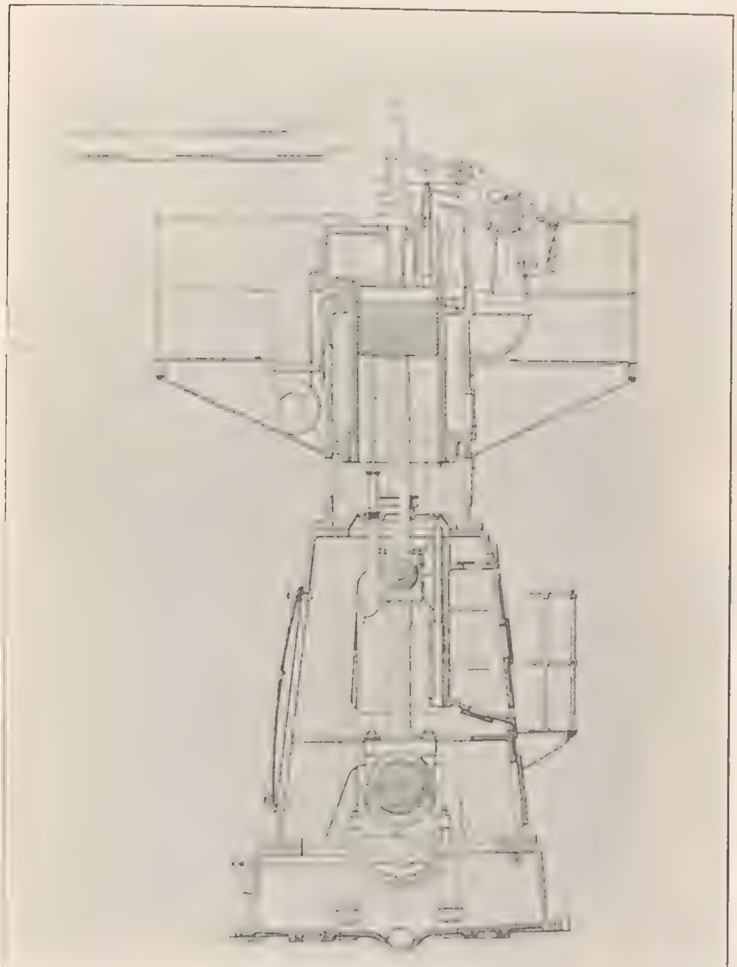

Fig. 1. Werkspoor Diesel Engine for Land Service. Prototype of Marine Diesel Engine.

meister and Wain of Kopenhagen. Up to 1910 all Diesel engines were designed with the long trunk piston in which the gudgeon pin was fixed, to which the connecting rod was connected. In

this Werkspoor engine (Fig. 1) for the first time a box-shaped short piston with piston rod, cross-head and guide was introduced, such as are now common practice.

In the very small experimental engine of Dr. Diesel, this design was also applied, but Diesel so little realized the advan-

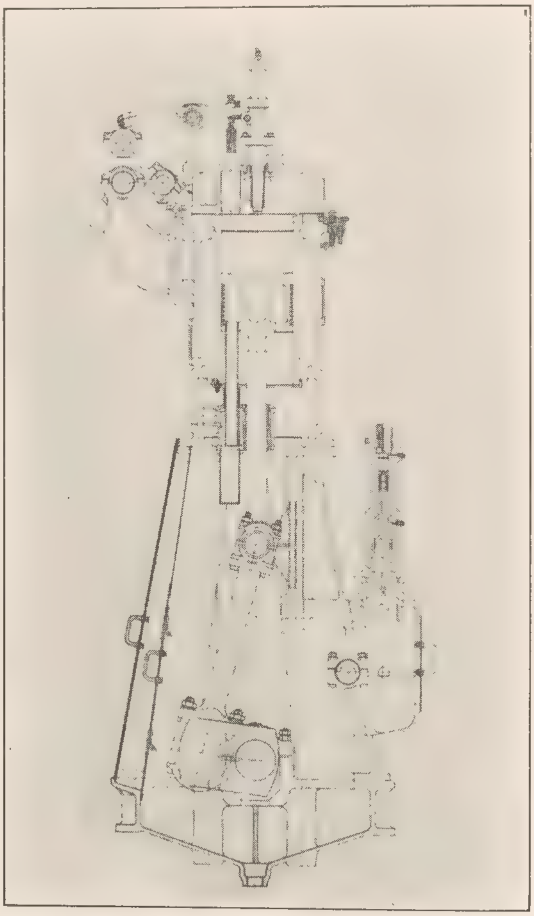

Fig. 2. Diesel Engine of "Vulcanus", Built by Werkspoor, Amsterdam.

tages over the trunk piston, that he expressed as his views at the meeting of Naval Architects of April 6th, 1911, in London, that for single-acting marine engines, the trunk-piston engine was to be preferred to the engine with short piston, piston rod with cross-head and guide. Furthermore, in this motor for the first time in a large motor were applied the four tie-rods around

each cylinder, coupling most directly the upward forces due to the pressure on the cylinder heads and the downward forces on the main bearings due to the pressure on the pistons. By these means it became possible to keep the cast iron frame, in which

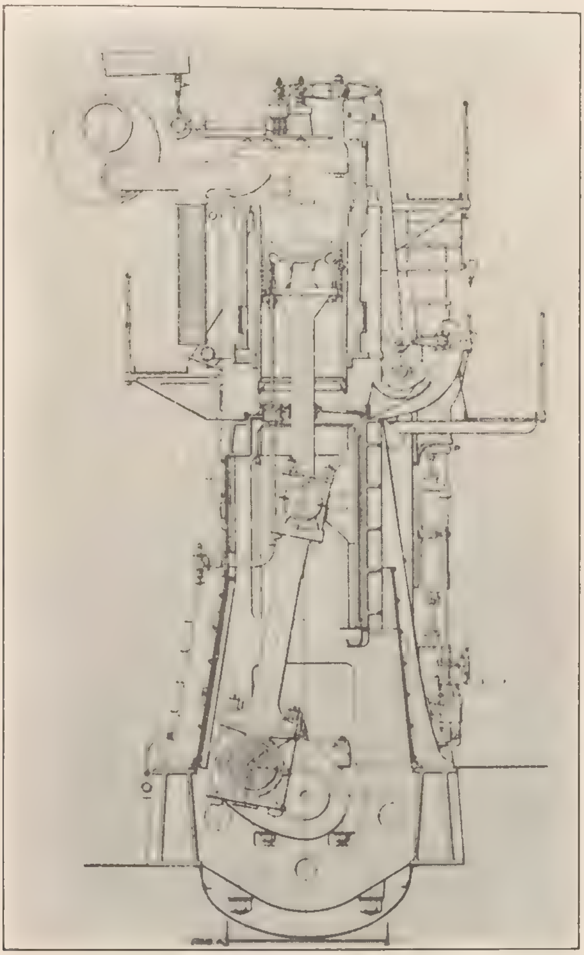

Fig. 3. Diesel Engine of the "Fionia", Built by Burmeister & Wain, Copenhagen.

the connecting rods move, very light and to provide for big apertures, as this box-shaped frame had to carry the weight of the cylinder only, no forces being transmitted through it.

This design is adopted in most of the later marine Diesel engines.

The "Vulcanus" engine of 1910 shows an improvement on the engine of the Brussels' Exposition. The cast iron doors in the frames covering the apertures in same are converted into sheet-steel splash guards covering the entire front, thus improving the accessibility.

One of the latest Burmeister & Wain engines, placed in the "Fionia" and built in 1913, shows the same construction (see Fig. 3).

After the small marine Diesel engines of Sulzer and Nürnberg, the six-cylinder engine of the "Vulcanus" came as the first full-powered reversible Diesel engine. This engine had a capacity of 450 b.h.p. at 180 revolutions per minute, the cylinder bore was 400 mm. (15.7 ins.) and the stroke 800 mm. (31.5 ins.). The ship is a 1000-ton tank ship owned by the Nederlandsche Indische Tankstoomboot Maatschappy and the hull was built by the Nederlandsche Scheepsbouw Maatschappy of Amsterdam. The engine was built at the Werkspoor Works of Amsterdam. The engine was ordered in 1910 and in December of the same year the trial trip took place.

In the beginning of her existence trouble was encountered with the air compressors and also through the lack of experience of the engine attendants. The ship has, however, completed successfully every voyage undertaken, among others a trip from France to Singapore without an extra stoppage at sea, and it is in permanent service in India at present, to the full satisfaction of the owners.

The engine of the "Vulcanus" is represented in Figs. 4 and 5. It is built in the same style as the Diesel engine of the Brussels' Exposition. The crank-shafts and guides are enclosed in a casing; the rear and side walls are made of cast iron and shut off in front by light steel sheets, that can easily be removed in order to inspect the main moving parts. For the big forces tie-rods are again applied, connecting the cylinder beam to the bed-plate. The latter is trough-shaped to collect the lubricating oil, that is then cleaned and used over again. The lubricating oil is forced to the bearings by a pump. The motion of the cam-shaft is derived from the main shaft by eccentrics and rods that work on a small crank-shaft that carries a pinion. This pinion works on two gear wheels of twice the number of teeth,

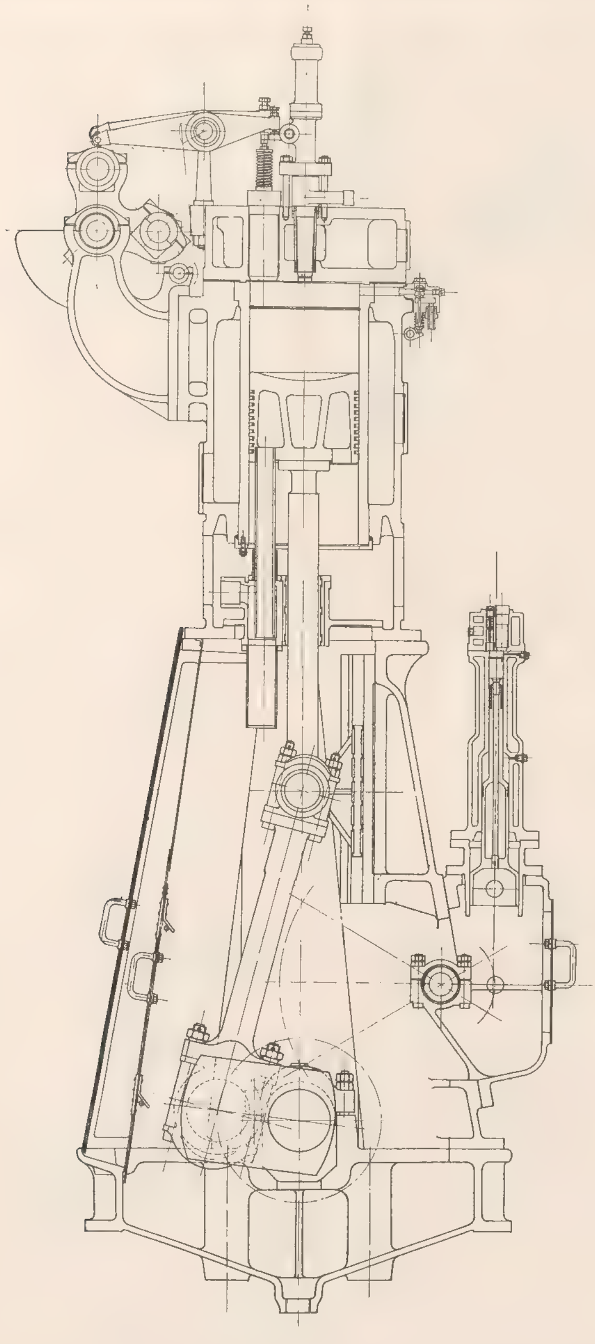

Fig. 4. Six-Cylinder Werkspoor Marine Diesel Engine of the "Vulcanus", 450 B.H.P. Cylinder Diameter = 400 MM.; Stroke = 600 MM.

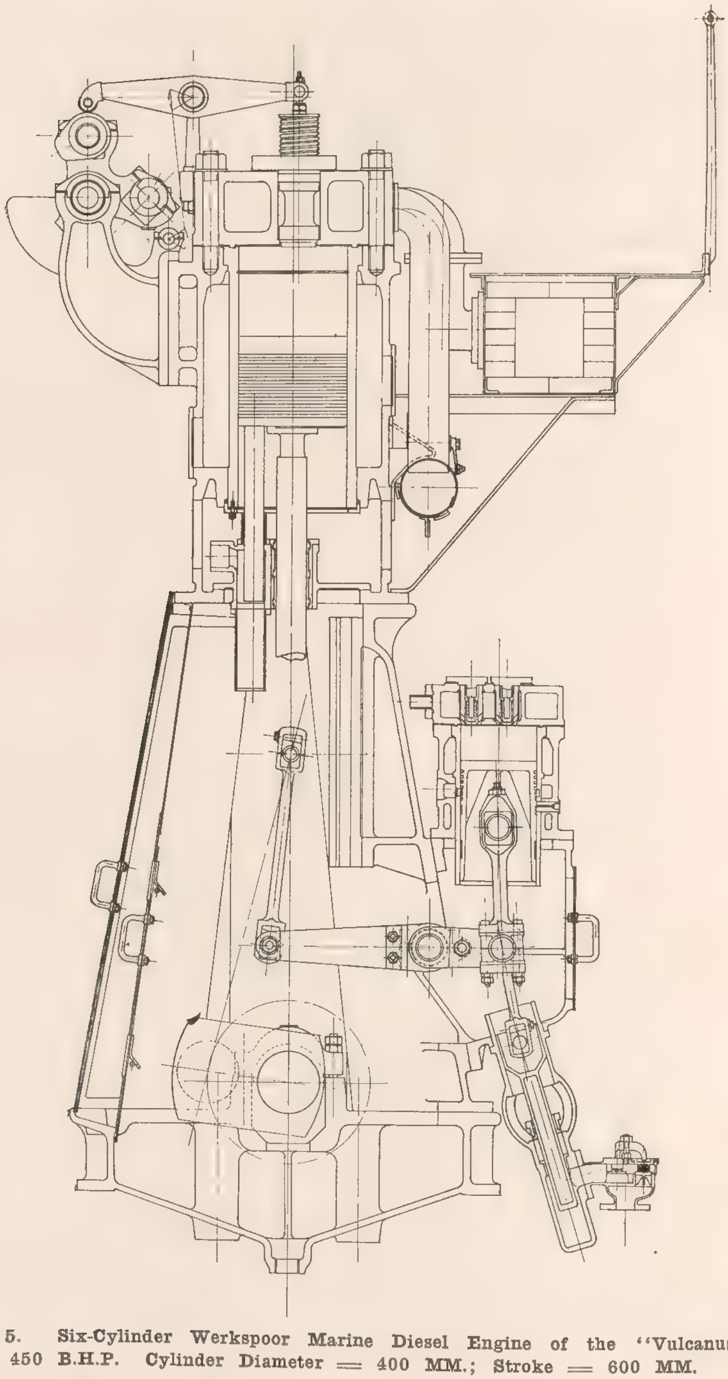

Fig. 5. Six-Cylinder Werkspoor Marine Diesel Engine of the "Vulcanus", 450 B.H.P. Cylinder Diameter = 400 MM.; Stroke = 600 MM.

thus reducing the speed of the cam-shaft to half of the engine speed, as is necessary in a four-cycle engine.

The cylinder beam carries the cylinder liners and on the top are fixed the cylinder heads. All the bearings for cam-shafts, rocker-shafts and the like are attached to the cylinder beam. The beam serves also as a water jacket.

The engine of the ''Vulcanus'' is directly reversible, there being two cam-shafts, one with the cams set for forward motion, the other for backward motion. The hand-wheel for the reversing is mounted on a handle case, where all the operations necessary for starting,, reversing, regulating and stopping can be controlled. It also carries a telegraph. The valves and levers in the cylinder heads do not differ from what is ordinary practice for four-cycle land Diesel engines.

The fuel pump shows an interesting feature. There is only one pump and one spare pump for the whcle engine. The oil is pumped into an accumulator, which stops the pump when full by keeping the suction valve open. The ''Vulcanus'' was first equipped with an accumulator, for this purpose, consisting of two plungers in line having different gauges. The smaller one worked through a stuffing-box in a cylinder containing oil, the larger one in a cylinder with air, directly connected with the air line for in-blast. The pump was automatically cut out by the motion of the plunger and then the latter forced the oil to the cylinders. When near its end position, it brought the pump into action again. This arrangement was soon replaced by another that incorporated the same advantages and omitted the stuffing-boxes. This arrangement is generally called the ''floating vessel''.

This vessel is placed high in the engine room. The bottom is connected to the delivery of the fuel pump and to the fuel inlet valves on the cylinder and the top is connected to the in-blast air line. This vessel is mounted on a balance with counter-weight, in such a manner that it will sink a few inches when full of oil and rise when empty; this motion is transmitted to the suction valve of the fuel pump, which is thereby kept open or left free, as the case may be. This arrangement requires the use of but one fuel pump for the 6 cylinders, as the distributors work perfectly with only a difference in pressure before and after the

valves in the distributor equal to the pressure of a few feet of oil column, according to the height of the floating vessel above the fuel valves in the cylinder heads.

Another advantage is the amount of fuel always ready for starting and in case a pump should get out of order. In such case there is plenty of time to start a spare pump before the engine stops from lack of fuel. This floating vessel has given great satisfaction. No troubles were ever experienced with the fuel supply with any of the Werkspoor marine engines, which is due to this arrangement.

The "Vulcanus" is now plying between the East Indian Islands, making short trips.

I here insert an interesting comparison made by the Marine Superintendent of the Anglo Saxon Petroleum Co. In his paper on "Liquid Fuel as a Source of Energy for the Propulsion of Ships and Its Proved Advantages Over Coal", read February 24th, 1913, before the Institute of Marine Engineers, he said:

"In comparing the enormous advantages derivable from oil fuel in conjunction with the Diesel ship with the use of coal in ordinary steamers, the following figures, obtained in actual working, the mean result of two years' running, may be found of interest. We propose to give a few comparative results obtained with the motor vessel "Vulcanus", which commenced service in February, 1911, and a steamer of slightly less carrying capacity, thus:*

	"Vulcanus"	S. S. "Sabine Rickmers"
Length B. P.	196′ 0″	200′ 0″
Breadth	37′ 9″	30′ 6″
M. D.	13′ 2″	18′ 9″
Draught S. M.	12′ 4½″	16′ 9″
Deadweight carrying capacity	1235 tons	1269 tons
Displacement	2080 tons	2290 tons
"Vulcanus"—Engines (6-cyl. 4-cycle, reversible Werkspoor Diesel, dia. 15¾″ x 23⅝″ stroke).		
S. S. "Sabine Rickmers"—Engines, diams. 17⅜″ x 28″ x 44½″; 27⅜″ stroke.		

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* The data and results are condensed from the original paper.

The following economic results have been shown in service:

"Vulcanus". Total running time on voyage, 8.26 days; total distance, 1530 miles; mean speed, 7.7 knots; average oil consumption per day of 24 hours, 2.06 tons; cargo, 976 tons; dead weight, 1112 tons.

"Sabine Rickmers". Total running time on voyage, 7.04 days; total distance, 1473 miles; mean speed, 8.7 knots; average coal consumption per day of 24 hours, 13.4 tons; cargo, 1013 tons; dead weight, 1225 tons.

A striking example of the advantages associated with low fuel consumption is to be found in the fact that the vessel recently completed a voyage of eighty-eight days without bunkering at any intermediate port. On this particular run she left Amsterdam on August 30 with 140 tons of fuel oil in bunkers, loaded a cargo at Constanza, Black Sea, for Cette, proceeded thence to Batoum, and arrived back at Amsterdam on November 27, a distance of some 10,750 miles. In the Bay of Biscay and North Sea, moreover, the "Vulcanus" was confronted by very bad weather. Nevertheless, six tons of liquid fuel remained on board at Amsterdam after the voyage. Thus the total consumption was 134 tons in 65.7 steaming days at 2.03 tons per diem.

The "Vulcanus" held for a full year the place of being the only full-powered sea-going Diesel-engine ship afloat, from the end of 1910 until the end of 1911, when the "Sembilan" built by Werkspoor for the Koninklyke Paketvaart Maatschappy came into service.

The "Sembilan" has a comparatively small engine, 200 b.h.p., in three cylinders of 400 mm. (15.75 ins.) bore and stroke of 500 mm. (19.68 ins.). The engine is reversible. The whole arrangement was built in the style of a much larger engine, as the owners wanted to make a trial with a small ship to get experience before they went in for the building of larger Diesel engines for their ships. The experiences with the "Vulcanus" have influenced the design of this engine. Many features that had proved to be good were retained:—the floating vessel, the tie-rods, the links for the cam-shaft motion. A novel feature was introduced, namely, the Werkspoor patent piston-dismounting device. The overhauling of the pistons was thereby much facilitated. The piston is dismounted from below, by simply lower-

ing the cylinder extension; no pipes need to be disturbed and the cylinder head can remain in place. Another improvement was the intermediate crank-shaft below, running at half-speed to drive the valve gear. With the "Vulcanus" the links moved with the speed of the engine; on the "Sembilan" they revolved with half that speed; besides there were three links, always in tension, whereas the two links of the "Vulcanus" engines were in tension and compression alternately.

The "Sembilan" proved very successful; she runs in East Indian waters, and her success induced the owners to order five more engine sets for larger vessels.

In February, 1912, the first marine Diesel engine installation built by Burmeister & Wain of Kopenhagen commenced work in the "Selandia". She is a twin-screw vessel with engines of 1000 b.h.p. each, four-cycle.

I will here insert the interesting results obtained with one of the later Burmeister & Wain engines, although we for a moment lose track of the chronological line observed in this paper.

By the courtesy of this concern I am enabled to give a comparison of the Diesel ship "Siam" with two steamships "Kina" and "Arabiën".

The economical question being all important for ship-owners, this comparison cannot fail to highly interest them.

The ships belong to the same owners, called Ostasiatisk Kompagni. The voyages are the first made by each ship.

S.S. "Kina" and "Arabiën" are single-screw ships of the following dimensions:

Length between p.p.	385′ 0″
Beam	53′ 0″
Draught	26′ 10¾″
Deadweight	8720 tons
Bunker capacity (coal)	770 tons

The "Kina" and "Arabiën" were built in 1911 by Swan Hunter & Wigham Richardson and engined with triple-expansion steam engines. They are the most economical steamships of the whole fleet of the Ostasiatisk Kompagni.

The Diesel-engine ship "Siam" was built and engined by Burmeister & Wain of Kopenhagen. The dimensions are:

Length between p.p.	410′ 0″
Beam	55′ 0″
Draught	30′ 6″
Deadweight	9700 tons
Bunker capacity (oil)	1250 tons

The voyages made by these ships are the same, so that the results are well suited for comparison.

S.S. "Kina", first voyage, 6/16/1911 to 11/25/1911.

Full outbound load in Antwerp	8720 tons—1162 tons = 7558 tons cargo
Full homebound load from Sabang	8720 tons— 932 tons = 7788 tons cargo
Mean cargo	7673 tons

Diesel-engine ship "Siam", first voyage, 4/9/1913 to 10/4/1913.

Full outbound load in Antwerp	9500 tons— 493 tons = 9007 tons
Full home load in Hankow	9500 tons—1168 tons = 8332 tons
Mean cargo	8670 tons

From the engine room report of these two ships, the following data are of interest:

	S. S. "Kina" 1st voyage	D. S. "Siam" 1st voyage
Duration of trip	163 days	182 days
Time passed at sea, engine working	109 days	107.5 days
Time passed in harbour	54 days	74.5 days
Distance in miles	27,808.0	27,818.0
Number of hours regular running	2,517	2,497
Manoeuvring	92	82
Mean speed, knots	11.0	11.14
Number of hours auxiliary engine running		St'bd 2,127.5
Number of hours auxiliary engine running		Port 1,666.5
Fuel consumption per mile	174.5 kg. coal (384.6 lbs.)	40.25 kg. oil (88.7 lbs.)
Lubricating oil consumption per i.h.p. per hour	0.206 gr. (.0072 oz.)	1.64 gr. (.0577 oz.)

	S.S. "Kina" 1st voyage	D.S. "Siam" 1st voyage
Fuel consumption for firing up	49.6 tons	0
Stand-by losses	31.6 "	0
For full steam no propulsion	7.8 "	0
Regular propulsion	4,415.0 "	1,061.98 tons
Manoeuvring	71.9 "	14.74 "
Electric light	59.6 "	19.04 "
Heating	10.7 "	0.6 "
Winches and pumps	179.6 "	23.84 "
Fuel for main engine	4,576.3 "	1,076.72 "
Fuel for auxiliaries	282.3 "	43.48 "
Total fuel consumption	4,858.6 "	1,120.2 "

Economic results for one round trip, Europe, East Asia and back:

Cargo	7,673	8,670
1000 tons of cargo carried one mile at a speed of about 11 knots at fuel consumption of	22.8 kg. coal (50.3 lbs.)	4.65 kg. oil (10.25 lbs.)
Price of fuel per ton	\$5.40 (coal)	\$8.60 (oil)
1000 tons of cargo carried one mile at a speed of 11 knots at fuel expense of	12.3 cts.	4.0 cts.
Total fuel expense for a cargo load of 8500 tons for transportation from Kopenhagen to East Asia and back (27,818 miles) at a speed of 11 knots	\$30,300	\$9,900

Attention is drawn to the following. The engine room attendance in S.S. "Kina" consists of:

3 engineers
2 assistant engineers
14 firemen

Total..............19 men

in the Diesel ship "Siam" it consists of:

4 engineers
5 assistant engineers
4 oil men

Total..............13 men

S.S. "Kina" bunkered coal 10 times on the voyage. D.S. "Siam" bunkered oil twice on the voyage; the last time so much that the ship on the next trip over the same route only needed bunkering once.

Diesel ship "Siam": Second voyage; trip around the world. From Europe, around South America to the West Coast of the U. S. A., from thence to Japan, China, Vladivostok and back through the Suez Canal:

Outgoing cargo	9500— 780 tons = 8720 tons
Cargo when plying between the West Coast and Japan	9500—1056 tons = 8440 tons
Homebound cargo	9500—1215 tons = 8285 tons
Average cargo for the whole voyage about	8500 tons

S.S. "Arabiën": Fifth voyage:

Outgoing cargo	8720—1555 tons = 7165 tons
Cargo when plying between the West Coast and Japan	870—1085 tons = 7635 tons
Homebound cargo	8720—1120 tons = 7600 tons
Average cargo for the whole voyage about	7500 tons

From the engine log book of these two ships the following items are of interest:

	S. S. "Arabiën" 5th voyage	D. S. "Siam" 2nd voyage
Duration of voyage	300 days	236 days
Time spent at sea, engine working	183 days	140 days
Time spent in port	117 days	96 days
Distance in miles	45,676	34,819
Number of hours regular running	4,278	3,279
Number of hours manoeuvring	109	88
Average speed, knots	10.7	10.6
Number of hours auxiliary engine running		St'bd. 2,665
Number of hours auxiliary engine running		Port 2,539
Fuel consumption per mile	186.4 kg. coal (410.8 lbs.)	41.5 kg. oil (91.5 lbs.)

	S.S. "Arabiën" 5th voyage	D.S. "Siam" 2nd voyage
Lubricating-oil consumption per i.h.p.-hour		0.866 gr. (.03 oz.)
Fuel consumption for firing up	66 tons	
Stand-by losses	77.5 "	
For full steam no propulsion	16.95 "	
Regular propulsion	7,600.75 "	1,357.9 tons
Manoeuvring	102.5 "	18.3 "
Electric light	149.75 "	23.4 "
Heating	49.25 "	27.5 "
Winches and pumps	395.25 "	18.9 "
Fuel for main engine	7,863.7 "	1,376.2 "
Fuel for auxiliaries	670. "	69.8 "
Total fuel consumption	8,533.7 "	1,446 "

Economic results for trip around the world:

1000 tons of cargo carried one mile at a speed of 10.6 knots at fuel consumption of	25 kg. (55.1 lbs.)	4.9 kg. (10.8 lbs.)
Price of fuel per ton	\$5.40 (coal)	\$8.60 (oil)
1000 tons of cargo carried one mile at a speed of 10.6 knots at fuel expense of	13.5 cts.	4.2 cts.
Total fuel expense for a voyage round the world covering 35,000 miles, which coincides with Diesel engine ship "Siam's" case of 8,500 tons at a speed of 10.6 knots amounts to	\$40,000	\$12,600

The steamship "Arabiën" bunkered 14 times during the voyage. The Diesel-engine ship "Siam" bunkered only 3 times during the voyage, and of these one was caused by a mistake in the execution of the order.

At the end of the trip the remaining oil was sufficient to carry the ship back to the oil-supplying port without bunkering under way. A saving of about 68% in fuel expenses is the practical result obtained with the use of the Diesel-engined ship on this voyage. This included all consumption needed for loading and unloading, lighting, heating, etc. The extra saving by

smaller crew, bigger cargo-carrying capacity of the Diesel-engined ship, etc., were not even taken into account.

The longer the voyages are without stopping, the more economical the Diesel-engined ships are.

The only condition in the choice of route to be taken for the Diesel-engined ship is that it should be such that the ship may enter ports where oil is available.

Resuming the chronological line I left after description of the "Selandia", I now have to put forward the "Eavestone", owned by Furness Withy & Co. The engine was built by Richardson Westgarth & Co., Ltd., Middlesborough, under license of Carels Frères of Ghent; the hull was built at Raylton Dixon & Co., Ltd., of Middlesborough. Her dimensions were 276 ft. by 40½ ft.; displacement, 4500 tons; carrying capacity, 8200 tons; speed, 9.7 knots.

One single-acting two-cycle Carels Diesel engine was installed, having four cylinders with 508 mm. (20 ins.) bore and 914 mm. (36 ins.) stroke. The power was 800 b.h.p. and the speed 95 revolutions per minute. She made her first trip of any distance crossing the Atlantic, but on her homebound trip had considerable trouble. New pistons and cylinder covers had to be sent out to her to continue her voyage, and arriving home she had to undergo heavy repairs. According to the most recent reports the engines are taken out of the ship.

Carels of Ghent have several licencees outside of Belgium, viz., Schneider & Cie, le-Creusot, who built two Carels engines for a full-rigged sailing ship called "La France"; they were 900 hp. each and served as auxiliary power. J. C. Tecklenburg of Bremerhaven have built a six-cylinder Carels engine of 1500 hp. for the "Rolandesck"; Reiherstieg, Hamburg, have built a six-cylinder Carels engine for the "Wotan"; this engine has 2000 b.h.p. The Clyde Engineering & Shipbuilding Co. of Glasgow built the engine for the "Fordonian", also Carels two cycle type. The Carels Co. themselves have built one or two engines for the British Admiralty.

None of these companies have built more than one set of engines, as far as I know, and I believe that the main reason for this absence of repeat orders lies in the adoption of the two-cycle principle for these engines; they must have met with too

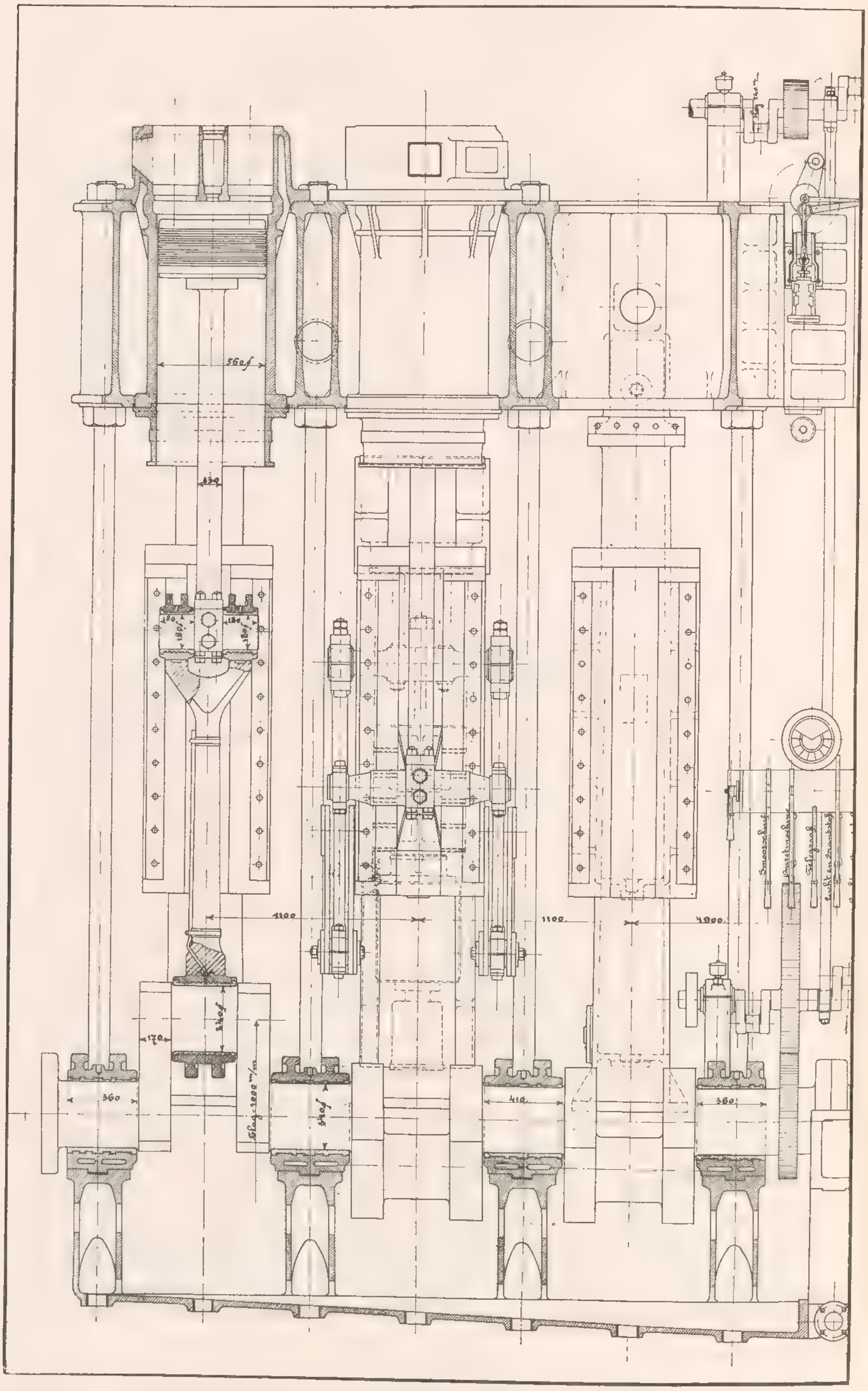

Fig. 6. Werkspoor Marine Diesel Engine, 1100 B.H.P. Half Side Elevation and Section.

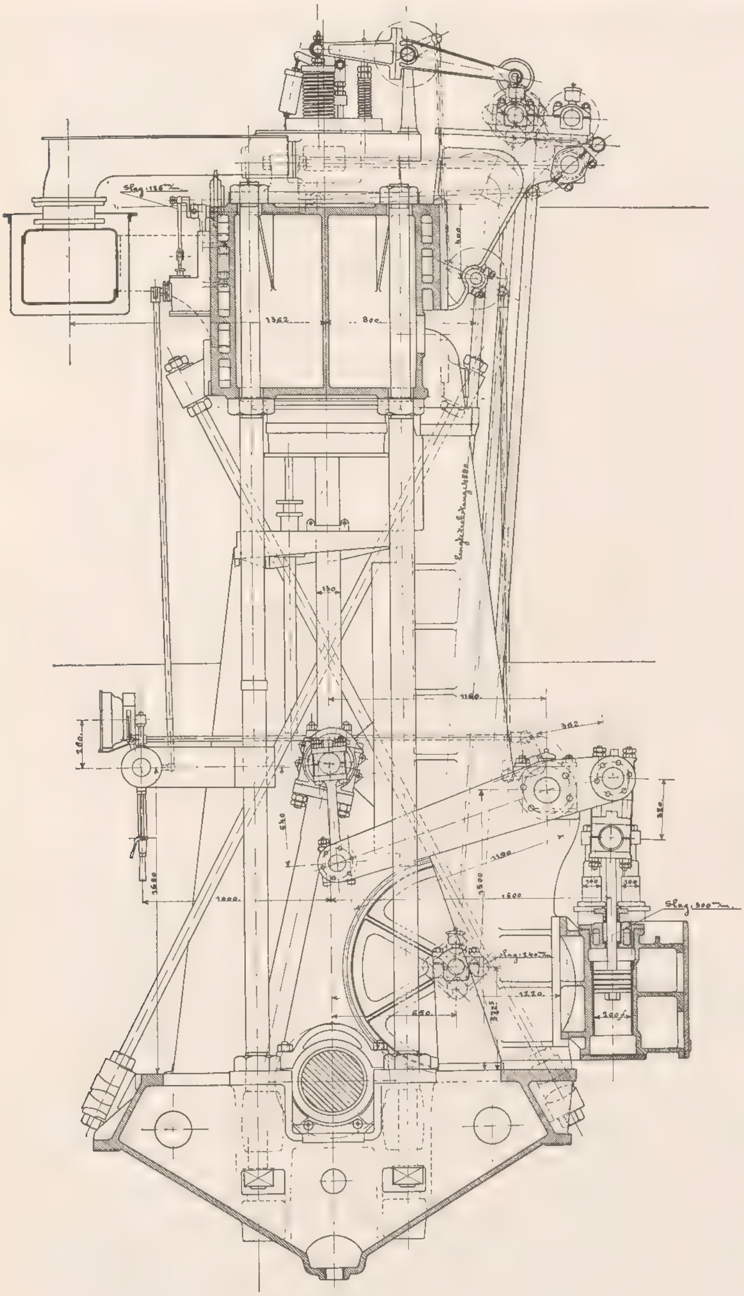

Fig. 7. Werkspoor Marine Diesel Engine, 1100 B.H.P.

many difficulties. In the year 1912 many Diesel-engined ships were put into commission. Outside of those already mentioned, there are the "Juno" with 1100 b.h.p. Werkspoor Diesel engine and the Emanuel Nobel with two such engines. Both are tank ships, for the former owned by the Nederlandsch Indesche Tankstoomboot Maatschappy, the latter by the Sociéte Anonyme d'Armement, d'Industrie et de Commerce of Antwerp. These 1100 b.h.p. Werkspoor engines have been repeated several times later and so are others of the same style but of different size. They represent the present day Werkspoor marine Diesel engine. On Figs. 6 and 7 diagrammatic views of this engine show the construction.

Some of the particulars may be put forward. Cylinder and cylinder head are cast in one piece (section shown in longitudinal view). A glance at the cut shows the very thorough cooling obtained by this design, especially at the hottest parts of cylinder and head as compared with the older design of the "Vulcanus" engine, where heavy flanges obstruct the passage of the water near the top of the combustion chamber, where most of the heat is produced. In the cylinder head are the customary apertures for the valves. The box-shaped piston is water cooled, for which purpose sea water is introduced by special telescoping pipes without glands. After circulating there, it is led through another set of telescoping pipes back to the sea.

The cylinders are supported three by three in a cast-iron cylinder beam. The two beams are connected by an intermediate piece.

The box frame of the "Vulcanus" engine has been entirely discarded, it being replaced by a set of steel columns, which secure accessibility combined with great strength and lightness. Cast iron frames carry the guides. They are fixed below to the bed plate by studs and nuts, but at the top there is no rigid connection to the cylinder beam; strips of steel prevent any horizontal motion, but vertical motions are not prevented. This has the following object: At each combustion the internal forces tend to elongate the steel tie-rods. If the cylinder beam were fixed to the cast iron columns the strain would go through these columns and bed-plate, which parts would then require to be far heavier.

Steel diagonals stiffen the engine in the horizontal direction and prevent vibration.

Steel splash guards complete this part of the engine.

Special attention may be drawn to the trays underneath the pistons, that catch the oil that may drop from the cylinder wall and drops of water wasted from the telescoping pipes that bring the cooling water to and from the pistons.

These trays, which are very effective, also serve to prevent the lubricating oil from splashing against the cylinder wall where it would otherwise be led by the pistons into the combustion chamber, causing a high consumption of lubricating oil.

The piston rods pass through the above-named trays, stuffing-boxes securing a good separation of the crank chamber, so that no water can ever drip in it. The trays also serve as supports for the telescoping pipes. The Werkspoor patent piston-dismounting device is here again applied, as also the floating vessel or fuel accumulator.

The main improvement this new type of engine has over the "Sembilan" engine, described before, is that the scheme of steel columns is worked out more completely in the "Juno" and "Emanuel Nobel" engine, whereas the "Sembilan" engine still shows a combination of steel tie-rods and cast iron frame. Fig. 8 illustrates the outer view of these engines.

In the "Emanuel Nobel" for the first time the waste gases were passed through a donkey boiler to give steam for steering gear, whistle and ship heating. As this proved a success, Werkspoor followed this construction in all its later ships.

In 1912 Messrs. Sulzer Bros. also put a set of engines in a ship. It was the "Monte Penedo". The two engines are two-cycle, single-acting engines with four cylinders of 470 mm. (18.5 ins.) bore and a stroke of 680 mm. (26.8 ins.); speed 160 revolutions per minute. The data of the ship are:

Length	107 meters (351 feet)
Beam	15.3 meters (50 feet)
Depth	8.2 meters (26.9 feet)
Speed	10 knots
Deadweight	4000 tons
Bunker capacity	700
Weight of engines and auxiliaries	160 tons
Power	1700 h.p.

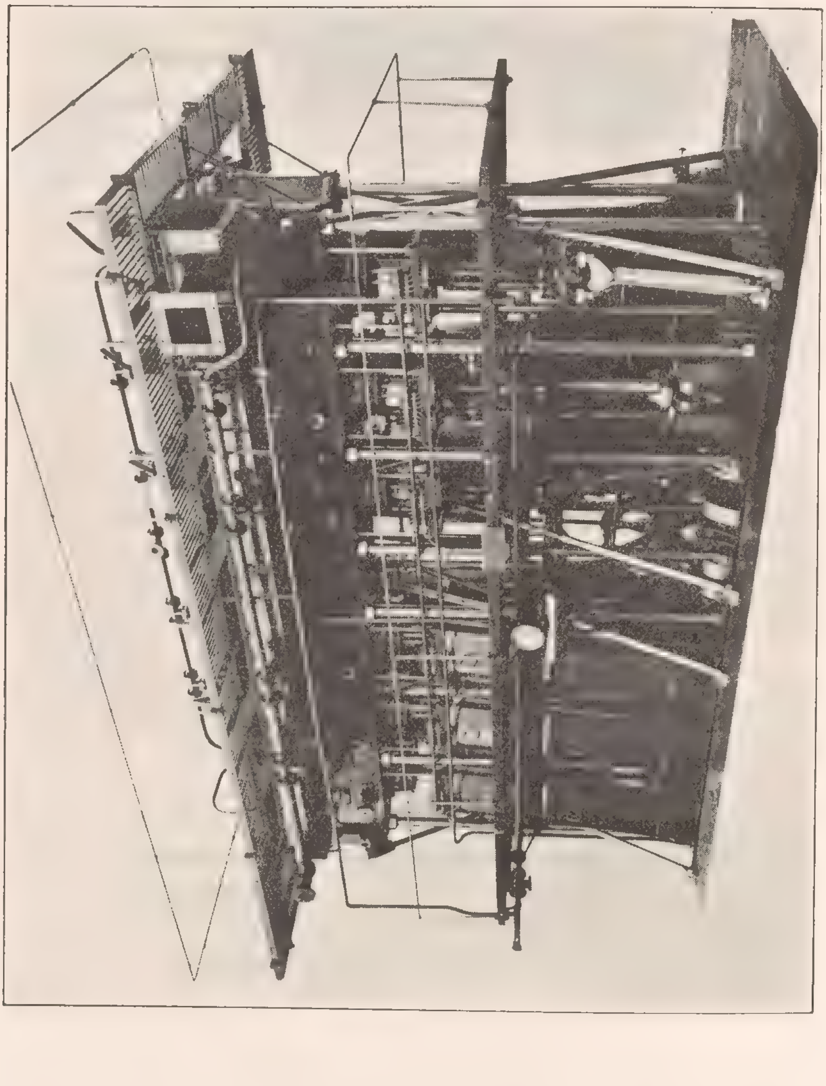

Fig. 8. Werkspoor Marine Diesel Engine, 1100 B.H.P.

The "Monte Penedo" engines are remarkable for the absence of inlet and exhaust valves. The only valves in the cylinder heads are those for fuel injection and starting air. It makes a simple cylinder head but involves complications in the cylinder wall. The exhaust takes place through openings in the cylinder wall forming one-half circle, whereas the other half of the periphery is taken by openings for scavenging air. Of those there are two rows, one above the other, and the communication between the air main and the top row of openings can be blocked by a double-seated valve. This arrangement serves to keep the scavenging air pipe closed at the beginning of the exhaust and then to keep it open after the exhaust is closed, thus preventing the exhaust gases from entering in the air line first and afterward securing an abundance of fresh air at the start of the compression.

The "Monte Penedo" is probably the most successful two-cycle marine motor at present in service. After some trouble with the pistons on the first voyage (the extension required to shut the exhaust and inlet ports worked loose) the construction was altered, and since then the motors have given full satisfaction. It must not be forgotten, however, that these engines were of the very best workmanship that can probably be found and were worked by a set of carefully selected engineers trained in the shop for a year in the operation of these motors.

An interesting engine in course of construction at Sulzer Bros.' is shown in Fig. 9. It is a 1600-hp. engine for a tank ship. The seats in the scavenge air line for the valves mentioned above are plainly to be seen in the cut. The resemblance of the lower part with the standard steam engines must appeal to marine engineers. At the closing of 1912 the "Fordonian", already mentioned, was brought into service. In 1913 the "Hagen" built by Messrs. Krupp started on her first trip. She is equipped with two single-acting two-cycle engines, each composed of 6 cylinders 480 mm. (18.9 ins.) bore and 800 mm. (31.5 ins.) stroke, running 140 revolutions per minute.

The ship's dimensions are: 122 m. (400 ft.) long, 16.15 m. (53 ft.) beam and 9.85 m. (32.3 ft.) depth; carrying capacity 8350 tons, speed 11 knots, weight of machinery 580 tons, which is much heavier than the four-cycle Werkspoor motors.

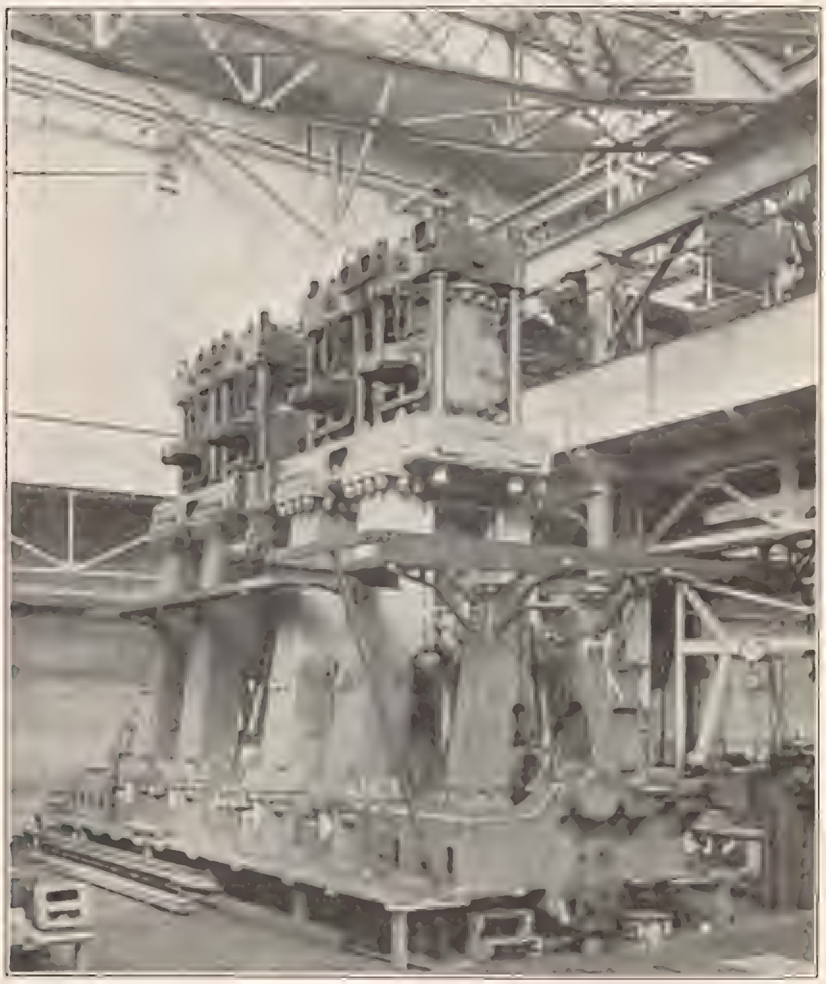

Fig. 9. 1600-HP. Engine Under Construction for a Tank Ship.

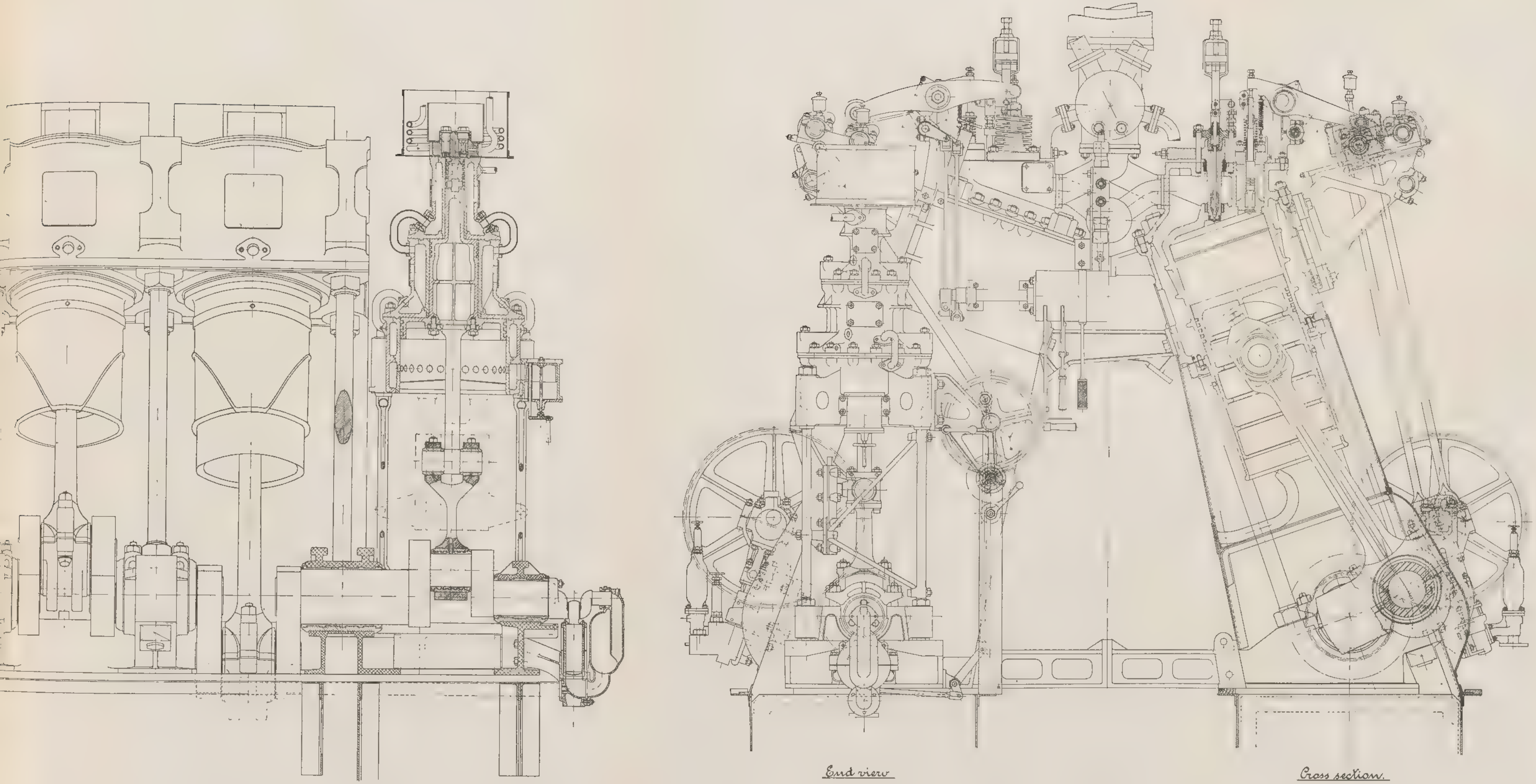

Plate. I. Part Side View and Section Through Air Compressor, and End View and Cross Section of 1200 B.H.P. Werkspoor Diesel Engine for a Gunboat.

In the same year, 1913, the sistership to the "Hagen", the "Loki", came into service.

The air compressors of the "Hagen", which are worked separately by auxiliary Diesel engines of 275 hp. each, have given considerable trouble. After the first voyage to New York more than three months were needed for repairs and one of the compressors had to be renewed. The next voyage brought cracked pistons. The "Loki" also had to undergo repairs, lasting a considerable time.

The "Wotan" with her Carels-type engines, mentioned before, also dates from 1913, but her running was stopped by the war.

The "Arthur von Gwinner" is fitted with two four-cylinder Junkers engines. The engines went through severe tests before putting them in the ship, then trials of considerable duration were made. The principle of the Junkers engine, reminding strongly of the Oechelhausen gas engine, has many attractions. The balancing of reciprocating forces, the absence of cylinder heads and stuffing-boxes are advantages of great importance, but difficulties have arisen with the cylinders, and the cooling of the pistons requires very difficult details. The ship had to repair very often before her working was stopped by the war.

To make this record of what has been done in marine Diesel motors as complete as possible, I give in Plate I some data of a very light engine, this being the only warship motor of which drawings were available. It is built for a small Netherlands gunboat by Werkspoor of Amsterdam.

The power in each propeller is 600 b.h.p. at 300 revolutions; the cylinder bore, 300 mm. (15.4 ins.); stroke, 500 mm. (19.7 ins.). The two engines are inclined towards the center of the ship to clear the armoured engine-room skylight and to form a triangle. The result is an extremely stiff engine, very accessible and as light as the lightest two-cycle motor of this power at these revolutions. Fig. 10 shows the outer appearance. Fig. 11 shows how easily a piston is dismounted. There is one cast-steel bed-plate for the two motors. This bed-plate which is of very light scantlings is connected by steel columns to the two lines of six cylinders, which are united to one block by a bolted flange over the full length of the motor. The weight of this twin motor, including flywheel, up to the thrust bearing is 33 tons.

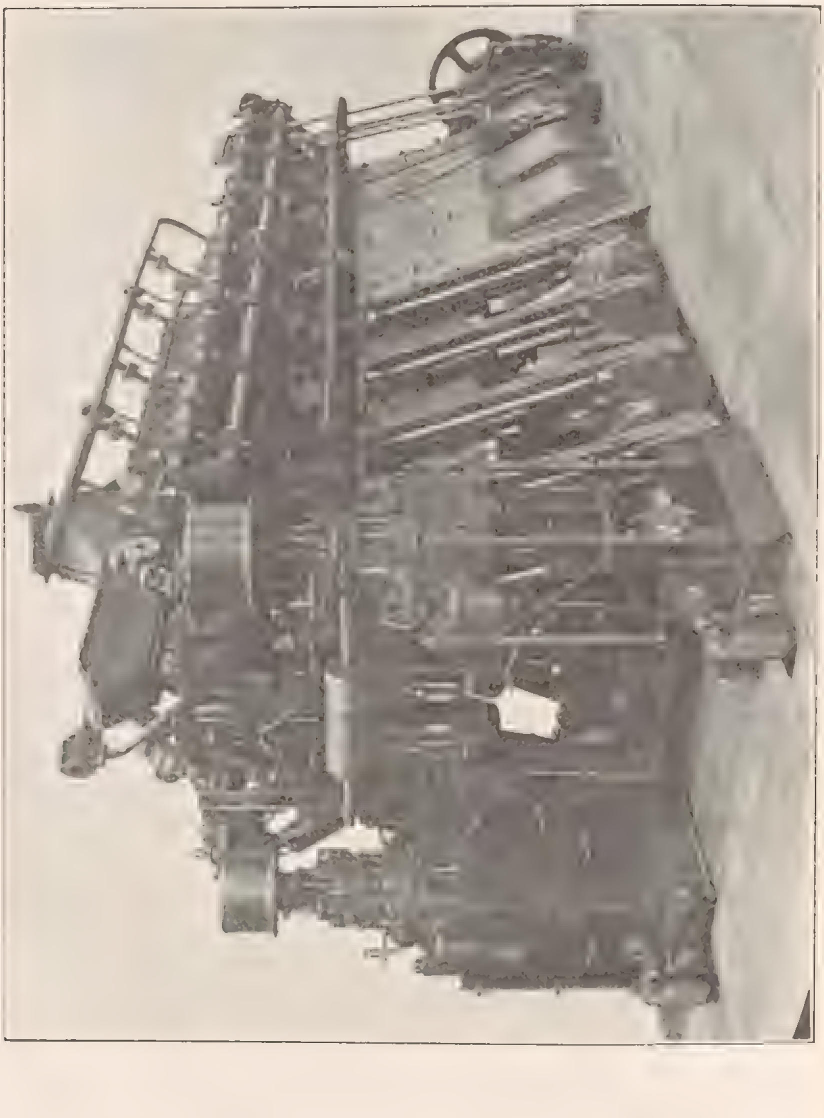

Fig. 10. Gunboat Engine.

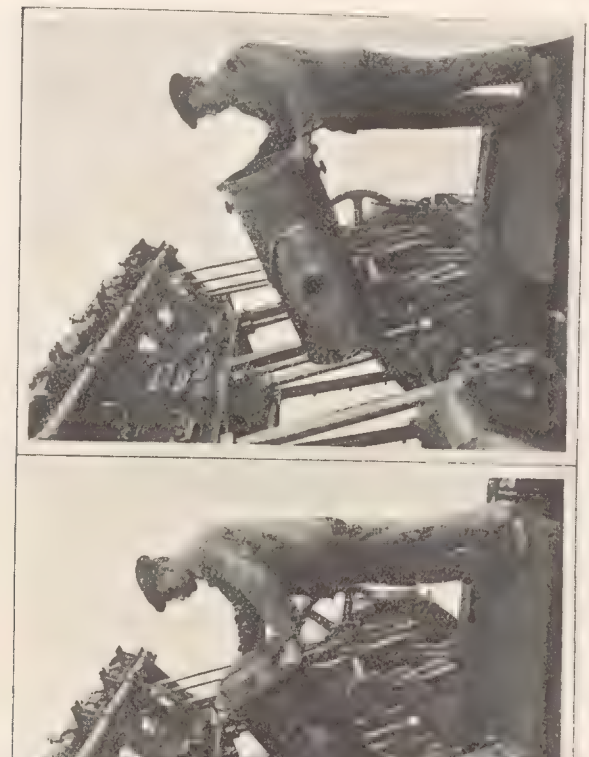

Fig. 11. Dismounting a Piston in a Gunboat Engine.

In 1914 we see that the increase of ships with motors is quite remarkable.

Burmeister & Wain of Kopenhagen delivered in 1914:

Name	Size of ship Length x beam x depth	I.H.P.	No. of screws
Pacific	362 ft. x 51 ft. 3 in. x 25 ft. 6 in. (110.3 m x 15.62 m x 7.8 m)	2000	2
Kronprince Gustaf Adolf	362 ft. x 51 ft. 3 in. x 25 ft. 6 in. (110.3 m x 15.62 m x 7.8 m)	2000	2
Fionia	410 ft. x 53 ft. x 38 ft. (125 m x 16.16 m x 11.58 m)	4000	2
Kronprincessin Margarete	362 ft. x 51 ft. 3 in. x 25 ft. 6 in. (110.3 m x 15.62 m x 7.8 m)	2000	2
Malakka	410 ft. x 55 ft. x 30 ft. 6 in. (125 m x 16.77 m x 9.3 m)	3000	2
Tonking	410 ft. x 55 ft. x 30 ft. 6 in. (125 m x 16.77 m x 9.3 m)	3000	2

Werkspoor of Amsterdam has delivered the engines for:

Name	Size of ship Length x beam x depth	I.H.P.	No. of screws
Elbruz	375 ft. x 40 ft. x 29 ft. (114.3 m x 12.2 m x 8.84 m)	2900	2
Ares	346 ft. 8 in. x 46 ft. 6 in. x 27 ft. 5 in. (105.7 m x 14.18 m x 8.36 m)	2300	2
Artemis	346 ft. 8 in. x 46 ft. 6 in. x 27 ft. 5 in. (105.7 m x 14.18 m x 8.36 m)	2300	2
Selene	346 ft. 8 in. x 46 ft. 6 in. x 27 ft. 5 in. (105.7 m x 14.18 m x 8.36 m)	2300	2
Hermes	346 ft. 8 in. x 46 ft. 6 in. x 27 ft. 5 in. (105.7 m x 14.18 m x 8.36 m)	2300	2
Jules Henry	305 ft. x 40 ft. x 23 ft. (93 m x 12.2 m x 7.54 m)	1350	2
Poseidon	185 ft. x 30 ft. 6 in. x 13 ft. 3 in. (56.4 m x 9.3 m x 4.04 m)	450	1

The Polar Diesel Engine Co., of Stockholm, delivered the twin-screw two-cycle engines of about 800 hp. each for the "Sebastian", built at Dundee, but they did not give satisfaction.

On the contrary, the troubles encountered were so great that after one voyage the engines are taken out.

In May, 1914, the ''Arum'', with English-built Polar-type engines, made her trials. The builders are Messrs. Swan Hunter and Wigham Richardson; the owners are the Flower Motor Ship Co. The engines are of the single-acting, two-cycle type. Each of the two engines has four cylinders, bore 410 mm. (16.2 ins.), stroke 860 mm. (33.9 ins.), speed 135 revolutions per minute, power rated at 650 b.h.p. each. The principal dimensions of the ship are 360 ft. by 47 ft. by 27 ft. depth, 22 ft. draft, carrying 550 tons. After performing various short trips, the ''Arum'' was sent on her first long voyage to the Persian Gulf, which was perfectly successful according to reports we obtained.

The German motorship ''Secundus'' started her career equally in 1914. The owner, Hamburg American Line, now possesses two motor vessels, ''Christian X'' and ''Secundus''. The former has four-cycle Burmeister & Wain engines, the latter has two-cycle engines built by Blohm & Voss of Hamburg. Each of these two engines has four cylinders of 600 mm. (23.6 ins.) bore, the stroke is 920 mm. (36.2 ins.), speed 120 revolutions per minute, power 1850 i. h. p. per engine.

The scavenging air is produced by a pump worked by levers off one of the cross heads. The air enters the cylinders through 4 poppet valves in each cylinder head.

The exhaust gases leave the cylinders through openings in the cylinder walls and a water-cooled pipe. The lower part of the engine resembles a steam engine, but forced lubrication is employed; the main crank-shaft bearings are water cooled. The pistons are cooled with fresh water, which I consider an unnecessary complication.

The ''Secundus'' made one complete voyage from Hamburg to New York and back. At the outbreak of the war she had not started her second voyage and is now therefore presumably at Hamburg.

The results obtained with a few non-reversible engines of 350 b.h.p., driving propellers with reversible blades, by Werkspoor, promise a great future for such engines for medium size crafts. A photograph of such an engine is shown in Fig. 12.

The reversing of the blades is performed with the aid of the

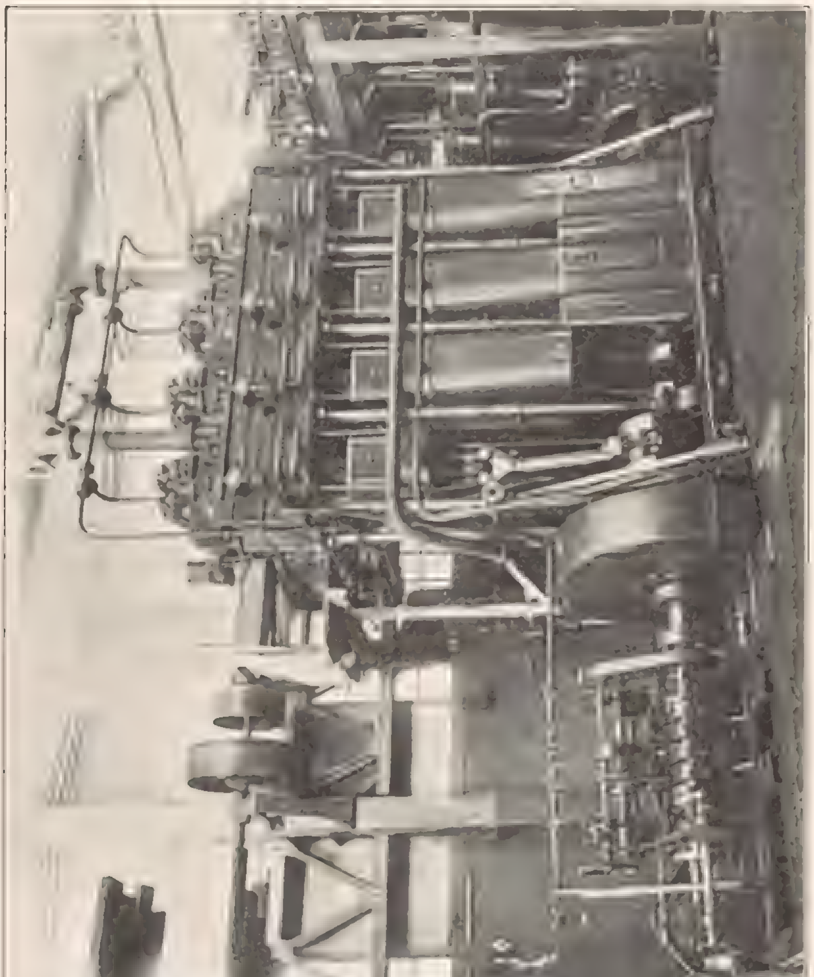

Fig. 12. Poseidon Engine.

Fig. 13. Propeller with Reversible Blades.

engine power; the gear is shown in Fig. 12 and the propeller in Fig. 13.

The advantage of this device is the excellent security of manoeuvring, which is controlled directly from the bridge.

The installation is of course far simpler than one with reversible engines. The manoeuvring air reservoirs are cut out and the auxiliaries are of a far simpler nature.

In designing a motor ship an important question is, how to drive the deck-machinery and the auxiliaries in the engine room. When plenty of money and a very good personnel are available, the best system is to make electricity by Diesel motors, and drive everything electrically. Where fuel to heat a boiler is very expensive, this system is also the most economical in the long run. In first cost it is, however, the dearest, and a staff of engineers is required who can tackle a great many novelties at once. To save first cost and to keep the novelties in the ship within the smallest limits, the best plan is to have two donkey boilers. Fire them either by coal or oil, depending on the price, and drive everything by steam, also the air compressor required to manoeuvre the main motor. When the ship runs several days continuously and the motor is four-cycle, the waste gases can heat the donkey boiler, giving plenty of steam for steering and for the whistle. The gain is about 1 ton of oil per day for ships of about 6000 tons. In short runs, or when the motor has to slow down often, this system cannot be applied. To drive the auxiliaries by compressed air has not proved a success; the air compressors must be too large. In tank ships it is a good system to make the main cargo-discharging pump centrifugal and drive it by a Diesel motor. The same motor can then drive the air compressor for manoeuvring. This system is slightly more expensive in first cost, but, when the ship has to unload often, it is cheaper in service than steam pumps. It also permits the ship to unload the cargo when it would be dangerous to fire a steam boiler.

A few things may yet be said of the fuel question.

The fuel question is one of great importance when discussing the merits of the marine Diesel engine. In the first years, the builders of these engines prescribed the use of solar oil, a distillate of petroleum having a specific gravity of not more than

0.88; a flash point of 80-100° Centigrade (180-212° F.); and a lower calorific value of at least 10,000 calories per kg. (18,000 B.t.u. per lb.).

Most of the Diesel engines up to the present day have run on oil of approximately this composition, but gradually other heavier kinds have come into use.

The principal of these latter is the Tarakan oil, which has been used for different long runs of motor ships, and has given perfect satisfaction to the users. The only inconvenience is that the starting of the motor is not always certain, so that some shipowners prefer to use solar oil when manoeuvring, even if Tarakan is the usual fuel.

Some characteristic data regarding this oil are:

Specific gravity 0.955. Flashpoint app. 100° Centigrade (212° F.). Calorific value 9900 calories per kg. (17,800 B.t.u. per lb.).

It contains some water and asphaltum (1.4% insoluble in aether-alcohol).

As can be seen from these figures, the oil is far heavier than the ordinary solar-oil brands, owing to the asphaltum and other heavy parts.

Although it was first thought that asphaltum in the fuel prevents the complete combustion and it was feared that it would cause deposits on the exhaust valves and the piston, extensive tests proved conclusively that, when the motor is in good working order, the exhaust is perfectly clean and no trace of deposit is found even after prolonged, continuous running.

Afterward it was found that it was possible to burn oil containing a very high percentage of asphaltum without any trouble, as the temperature within the cylinder of a Diesel engine, at the moment the oil is introduced, is high enough to start the combustion. The combustion once started, the temperature rises so high that when care is taken to mix the atomised fuel thoroughly with the air, practically all kinds of oil can be burned in a Diesel motor.

That really all kinds of oil of the most widely differing places of origin can be used, will be seen from the following table, giving the characteristics of various kinds of oil which have given good results in a Werkspoor stationary Diesel engine.

Name	Specific gravity	Flashpoint deg. cent.	Distillation Percentages to 300°	from 300°–350°	residue
Solar oil	0.88	99	79	17	4
Solar oil	0.857	95	10.4	50	39.6
Solar oil	0.856	92	82	14	4
Mixture Persian liquid fuel and Roumanian distillate	0.897	64	35	46.5	18.5
Solar oil	0.903	105	37	34	29
Solar oil	0.922	130	17	40	43
Solar oil	0.91	152	15	40	47
Residue	0.914	98	48	23	29
Residue	0.95	107	13	46	41
Masout (Batoum)		82	91	7	2
Heavy solar oil	0.913	138	36	57	7
Tarakan oil	0.955	103	41	24	35
Texas oil	0.905	123	30	40	30
Californian fuel oil	0.962	118	22.5	55.5	22
Egyptian residue		170	10.5	50	39.5
Trinidad crude oil		122	26.0	44.5	29.5
Mexican crude oil		105	26	33	41

All these oils have been used with success. For the heavier ones it was necessary to construct a special type of sprayer, which atomises the oil more effectively, and to heat the oil in the tanks and the pipes to and from the fuel pump to diminish the high viscosity. Oils having a viscosity of more than 7° Engler have to be heated before use.

On the heavier oils the motor cannot be started, so that it is necessary to change the motor before stopping to solar oil till the pipes and fuel pump are filled, so that on starting again the motor is ready.

This is, in main lines, the history of the Diesel motor as applied to merchant ships to the present time. It has proved that this engine, if well designed, well made and well attended to, is reliable enough for the longest voyages and is at least four times more economical in fuel consumption, weight for weight, than a coal-fired steamship, or nearly 3 times more economical than an oil-fired steamship.

The short history has also proved, in my opinion, that it is more difficult to make a reliable two-cycle motor, under the normal sea attendance than a four-cycle.

Probably the two-cycle motor will in the future become cheaper to make than the four-cycle for the same power, although the results thus far have not shown it. The running economy of the latter is the greater, especially when the waste gases are passed through a steam donkey-boiler as is done in the last six Werkspoor ships.

The cost to make a good marine motor is, and will remain, probably, about 1/3 higher than to make a good reciprocating steam-engine of the same power, but this higher price of the motor is partly compensated by the cheaper ship, because the motor takes up less room and weight than the steam engine and the bunkers can be made very much smaller. This latter saving depends on the distances or intervals between the places where it is economical to fill up bunkers.

The large motor ship requires fewer men to run than the large steamship; the quality of the men must, however, be higher. Difficulties with the troublesome firemen are eliminated; but the motor, if not very well attended to, is apt to require more repair in harbour than the steamship.

Balancing these good and bad qualities of motor- and steamships, the fuel price in the parts of the world where the ship has to run will generally decide to which side the balance will incline. In special cases, however, the fuel price will not be the main factor to be considered, but the following properties of the motor-driven ship are of greater value. That it does not require any warming up of boilers or engines. Even if nobody has been on board in advance, the motor ship can start at full speed as soon as the oil tanks are filled. That it is possible for a motor ship to bunker only at very long intervals, three or four times longer than a steamship. And last, but not least, that motor ships can be made in which the part of the ship where the engines are placed is of absolutely the same temperature as the other parts of the ship. In hot climates this quality will go far to turn the balance when the engineers have a say in the decision.

Paper No. 217

CARGO HANDLING METHODS AND APPLIANCES.

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INTRODUCTORY.

It is the desire that this paper should be of practical service, if only to a small degree, to all who are interested in marine affairs, not only to the naval architect, the marine terminal engineer, the ship owner, the president, the manager and the superintendent of steamship lines, the shipper and consignee, but also to the harbor and dock boards, the port authorities and commissions.

THE QUESTION.

The question, What are and what will be the cargo handling methods and appliances best adapted to the conditions of the inland and ocean ports of the United States, should be answered in such a way as to be of applicable value. To reduce the ship's detention in the harbor to the minimum, (for the ship tied to the pier is a liability, not an asset); to obtain the greatest return from the marine-terminal investments in piers, quays, machinery and buildings, and yet reduce the port charges to such low figures that they will not be a burden on commerce; to change the present methods so that the cost of transference and of handling at terminals will not be, as it often is, more than the water carriage between the ports; these are the objects of this paper.

It is not sufficient to describe isolated and existing installations, which may not be those best adapted for general ser-

vice, but rather to trace the progress of improvements and to show the trend of development, and from a presentation of this study, to make suggestions for standard methods and appliances.

The high cost of the present methods of handling miscellaneous cargoes and the time required to discharge and load vessels, in comparison with the results obtained at foreign ports, indicate the necessity for this study and recommendations.

Vessels and Shore Appliances.

There are two general classes of cargo-transferring machinery—those on the ship and those on the shore. Both are essential.

Cargo Classifications.

There are in general two kinds of cargoes to be handled; first, the miscellaneous, composed of merchandise of every description, generally known in railway transportation as package freight; and second, bulk material, as ore, coal, sand and rock, and cargoes composed chiefly of one commodity, as lumber and cotton.

As there are so many most excellent papers published pertaining to the transferring of bulk material, this paper will confine itself chiefly to the more advanced methods for miscellaneous cargoes, and will, at the end of the paper, describe the ore and coal and special commodity appliances by means of explanatory illustrations.

NOMENCLATURE.

There appears to be ambiguity as to the use and meaning of some of the words descriptive of marine-terminal elements, and for clearness the following definitions are suggested.

For example, the word "dock" is sometimes used for the word "wharf" and also for the water-slip where the vessel is berthed. It seemed best, therefore, to use the word "slip" for water space between piers.

The word "quay" is to signify the wharf parallel to the shore, and "pier", a wharf projecting into the waterway.

"Transferring" or "transference" refers to the freight movements between the vessel and the shore, between the shed

and the warehouse, or where there is one direct unbroken movement.

"Handling" is the general term to indicate the movements upon the pier and quay, or in the shed or warehouse, including assorting, distributing and tiering.

"Stowing" is the placing the cargo between decks.

"Shed," a building, usually of one story, erected on the pier or quay, which is used in handling and temporary holding of cargoes and designated respectively the "trans-shipment" and the "transfer shed".

"Warehouse", a building, generally of several stories, placed to the rear of the shed. The function of the warehouse is for long freight storage and it is equivalent to a storehouse.

"Burtoning", the shifting of the weight of a draft, or the draft itself, from one fall rope to another.

When the terminal is located along a comparatively narrow river, quays are constructed, but where there are broad water areas, piers are built extending into the waterway, either diagonally or at right angles to the shore line.

THE MARINE TERMINAL.

The elements of a complete marine terminal consist of piers, slips, quays, railroad tracks and various railway yards, sheds, warehouses, dray areas, open storage spaces, and often public markets, cold storage buildings, coal-pockets and manufacturing lofts. There are also sheds and warehouses for special commodities.

A modern terminal may comprise more elements, but these are enumerated so as to indicate the principal cargo movements.

CARGO TRANSFERRING AND HANDLING METHODS.

Between each of these elements and the vessel and cars there may be at any time an interchange of freight.

Before referring to the adoption of any type of mechanism, whether on the vessel or on the shore, the freight movements, or operating conditions, in the United States, may be briefly described, and their relative importance discussed.

The following are the principal freight movements, or methods, which require appliances:

(a) Between the ship and the open pier and the open quay and the shed or warehouse
(b) Between the ship and other ships or vessels (transshipments)
(c) Between the ship and cars
(d) Between the shed and the warehouse
(e) Between the ship and dray areas
(f) Between the cars and the terminal buildings

While the above are the general cargo movements, by following, in discharging, the course of one consignment, or mark, the possibility for improvement over existing methods is made clearer.

The bale, box or barrel may be between decks at some distance from the hatchway, as in the lower hold of a tramp steamship. The hook of the ship's fall rope, suspended from one boom, is attached to the package, and the load is drawn to and up through the hatchway above the height of the ship's rail, and is then burtoned to the hook of another fall rope, suspended from a second boom, and lowered upon a space of about eight to ten feet radius on the side of the pier. There are two winches and operators required for these services—one on the ship and one on the quay or pier—besides the rope man. The load is then assorted, distributed and tiered by manual labor. The weight of such a draft to be assorted is seldom above two tons, with general merchandise, and averages about one ton or less.

By means of the traveling gantry jib crane, at a terminal properly designed for the installation of mechanical appliances, the load is placed by one movement anywhere within a space of fifty feet radius, there being only one hoisting mechanism and one operator. This large space avoids congestion at the place of deposition.

As the weight of one consignment, or mark, averages, on steamships, from 1500 to 2000 pounds, it is, therefore, desirable to hoist in one draft one consignment only, and then burtoning, not to the fall rope of another boom, but to the hook of an overhead traveling hoist; thereby avoiding the assorting, distributing and tiering by manual labor, all such movements being made by machinery.

Transferring Mechanism on the Ship.

The most rapid transferring of the freight between the vessel and the shore does not depend wholly upon the transferring machinery, but depends also upon the design of the ships.

Influence of the Design of the Vessel on Transference.

Where there can be a clear vertical lift of the cargo from the hold of the ship and the elimination of the horizontal movement between the decks to the hatchways, there can be an average saving of over fifty per cent in the cost and in the time of transference.

As there are often twelve to fourteen men, and sometimes even more, in the hold at each hatchway to perform this horizontal movement and to attach the hooks, it will be seen that the above statement as to the saving is conservative.

To secure this vertical lift, hatches have been made longer and wider and, in length, nearly continuous, and in breadth almost equal to the ship's beam. In the interior of the ship there are now large clear spaces, as the decks are not supported by many small pillars but by longitudinal girders under the beams.

Ships for Special Commodities.

For such commodities as lumber, ore and coal, special ships have been designed with almost continuous hatches to facilitate the rapid loading and discharging of cargoes by direct vertical movements.

Special Appliances.

Many special handling devices have been proposed and some have been installed on ships, as the coal bridges on the U. S. Colliers "Jupiter" and "Jason" which have been used for packages, and revolving derricks. In one of the latest reports of a commission of the United States Army Engineers there is recommended, especially for inland waters, that the transferring appliances on ships be as few and as simple as possible.

The Steam Winch.

The steam winch still remains the favorite type of such cargo-handling appliances. The winches have been enlarged from a single 6-inch by 10-inch winch at each hatch, to a pair of 8-inch by 12-inch winches.

The derrick boom is now a steel tube of 5-ton capacity with a 25-ton machine at the end of the vessel. The diameter of the drums has been increased to 24 inches, and the steam pressure doubled.

These derrick booms are attached not only to the masts but to separate columns and to hollow steel tubes, which also serve for ventilating pipes.

Burtoning.

The general rule for ocean freighters is for all drafts to be burtoned; that is, the load is transferred from one boom to another, either by shifting the weight or by transferring the load from the hook of one fall rope to the hook of another. By this latter method, while one draft is being hoisted from the hold another is being lowered to the deck of the pier, or quay, thereby effecting a saving of nearly one half of the time, as two drafts are in motion at the same time.

Increased Size of Ships.

The increase in the tonnage capacity and in the costs of modern ships makes it imperative that on the ship, or on the shore, nothing should be left undone to reduce the time of the ship's detention at ports.

By means of the ship's winch, there averages in the discharging about twenty drafts per hour. This could be increased were it not for the limited space served on the pier alongside, generally a space of not more than ten feet radius, and, unless there is an excess of hand-truckmen, the congestion at this point is generally the limiting speed factor.

Under the head of ship's machinery may be included floating cranes and floating derricks; barges and lighters with shear-legs and various steam, electric and gasoline hoists; floating coal-transporters; portable coal conveyors with suspended chutes; and mast-booms with grab-buckets and grain elevators.

Floating derricks are used for excessive weights, and where there are no lifting appliances of sufficient capacity on the ship.

Side Ports.

Coastwise ships frequently load and discharge by manual labor, with hand-trucks, through side ports.

Costs Per Ton Handled by Manual Labor.

The following figures, taken from the House of Representatives' Document No. 226, 63d Congress, 1913, show the expense of this method of operating, through side ports, as given by the Southern Pacific Company, at New Orleans.

"The average cost of handling for the year ending December 31st, 1910, was 54.85 cents per ton of 2000 pounds, reduced to a basis of 30 cents per hour for labor. Thirty cents per hour is paid for straight labor and 40 cents per hour for night and Sunday work".

The men are assisted at berths Nos. 1, 2, and 3 by five electrically-driven ramps, which are approximately 70 feet long and are each driven by 15-horsepower motors at a maximum speed of 225 feet per minute.

This document also states:

"In addition to taking twice as long to handle cargo, the cost of operating through overall hatches and with manual labor would be, without the use of conveyers (ramps), approximately 25% greater."

This would make the cost of transferring and handling miscellaneous freight through the overall hatches 68.56 cents per ton. It is claimed by the agents of ocean liners that the cost is much less through overall hatchways than through side ports.

This may be due to the time the hand-truckmen are within the ship waiting to deliver or receive a hand-truck load of about 250 to 300 pounds.

Speed of Transference.

"The steamship 'Antilles' which was docked at 8:30 a. m., January 25th, 1913, discharged a load of 1725 tons in 11½ working hours, or an average of 150 tons per hour, employing 355 men". This would be at a cost of transferring at 70 cents per ton passing through side ports and handling by manual labor.

This same ship, "Antilles", was loaded with 2831 tons in 21½ working hours, or an average of 130 tons per hour, employing 200 men.

The cost on the "Antilles" through side ports was 70 cents per ton and the cost through overall hatchways would have been 87.50 cents per ton (estimated).

The maximum recorded speed per hour was 150 tons in discharging and 131 tons in loading.

In the year 1912, 581,172 tons were thus handled at New Orleans over 2100 lineal feet frontage, or about 276.75 tons per lineal foot. This result, with the operation confined to manual labor, shows excellent management and compares most favorably with other cities per lineal foot transferring capacity. New York averages only about 150 tons per lineal foot.

The above figures of cost through side ports and through overall hatchways, and the speed of transference and of handling, should be compared with those given later for the traveling jib gantry and overhead traveling hoists.

The continuously increasing size and carrying capacity of freighters are causing marked changes in the design of machinery and methods of operating.

Dimensions of Freighters.

A common size of the large ocean freighters may be taken as 500 to 600 feet in length, weighing about 7000 tons and carrying 8750 tons of cargo. The dimensions and carrying capacities are used in determining berthing lengths.

Reducing Ship's Detention.

Every day that can be saved in the detention of such a ship may be said to represent a saving of $600.00. A distinction should be made between the passenger ships of the North Atlantic and the freighters, in reference to length and freight-carrying capacity.

The following is the advance of the dead-weight carrying capacity of the vessels of one line of cargo tramps:

In 1895	6400 tons
In 1913	9600 "

It is expected that freighters will next increase more in beam.

SHORE APPLIANCES AND TERMINAL DESIGN AND LAYOUT.

Not only is the ship being designed to secure rapidity of transference, but the plan of the quays and piers with the sheds and warehouses, and their relative positions to each other, is receiving attention, so as to secure the most expeditious transference and handling.

As rehandling produces congestion, and as even a moderate amount of congestion adds fifty per cent to first handling costs, all designs and plans aim to eliminate rehandling.

Principles of Marine Terminal Design.

Not many years ago there was no uniformity in the design or plan of marine terminals. No rules were accepted and on this account there is such a diversity shown in terminals in various sections of the United States. Where there were no accepted principles based upon experience with cargo-handling appliances, there naturally occurred a copying of some nearby wharves, often of an obsolete type, and these were generally those of some larger city.

From a study of quays, piers and the machinery at foreign ports, compared with those in this country, it became evident that in order to secure the quickest movements of mixed cargoes to and from ships, the design of the whole terminal was an important factor.

As a result of many reports of the Federal Government, of states, cities and of engineers, and from visits by the writer to many ports, the following principles of terminal design were derived; and these principles may be said to indicate what is the trend of development and progress now being made in the United States, and by following them, mechanical appliances may be installed to advantage.

It can hardly be stated that these principles have been extensively adopted; but this is due to the fact that, except for special commodities, all terminal construction has been slow. With the advent of the new interest in a merchant marine, and the extension of foreign commerce, it is expected that the progress during the next few years will more than equal that of the last twenty-five. It may be said that this progress is being based upon foreign methods as the result of their experience, but adapted to American conditions.

The diagrams given later illustrate the general plan of a terminal, along an inland river, equipped with mechanical appliances.

Between the water's edge and the shed there should be a width of about 35 to 45 feet of quay; 35 feet for two lines of tracks, and 45 feet for three lines. To the rear of this quay

space is the shed, usually of one story, from 60 to 80 feet in width, from 400 to 500 feet in length and with from 30 to 40 feet of clear space beneath the cross girders. The warehouse, of a width of 80 to 100 feet, 4 to 6 stories in height and equal in length to the shed, is placed behind the shed, and parallel to it, at a distance of 45 to 60 feet. In the space back of the warehouse are dray areas, open storage spaces and additional railway tracks.

The space nearest the water, with railway tracks depressed to the level of the pavement, is spanned by a half- or full-arch traveling gantry jib-crane. Freight, if of few marks, can be swung directly from the car to the hatch of the ship at a cost of about three cents per ton, for the mechanical movement only, and 40 to 60 full drafts per hour are possible by one crane.

Each draft averages two tons in weight, which would be equal to about 80 tons per hour per crane. With two cranes per hatch and four hatches, the eight cranes would have a capacity of about 640 tons per hour. These figures should be compared with the record of the "Antilles" at New Orleans. Similarly, the load could be taken from drays in this quay space or from the side door of the shed.

With inbound cargoes the loads can be swung from the hatches to the side of the shed; but as only one consignment, averaging in weight between 1500 and 2000 pounds, is lifted in one draft, the hourly capacity is less than with outbound cargoes. These figures of capacity can be greatly increased if a large proportion of the cargo is of one material and of few marks.

With both this inbound and outbound freight, the movement, as described above, is only from or to the shed, cars or drays. There are the movements across and within the shed to within reach of the hook of the gantry crane, for which, including tiering, provision is made by the overhead movable cross-tracks in connection with the fixed side-tracks. On these travel the electric hoists, whereby it is possible to serve every cubic foot of space rapidly, and with continual succession of movements without any rehandling by manual labor.

The above includes mechanical assorting, distributing and tiering. The total cost from the hold of the ship and tiered in

the shed, using the cranes and traveling hoists, may average about fifteen cents per ton.

Between the shed and the warehouse, high, full-arch gantry-cranes will swing freight between the floor of the shed or the hooks of the hoists and any of the four or six floors of the warehouse. The load is brought within reach of the hook of the crane for burtoning by the traveling hoists.

For outbound freight, as stated, it is not generally necessary, according to the marks, to assort the freight; although it should be placed in the vessel according to its character or, if the vessel stops at different ports, to be placed for easy delivery at the different cities.

Miscellaneous inbound freight, however, should be first assorted, according to consignment, and then distributed and tiered.

Shed Capacity and Tiering.

It is a good rule to plan the shed for such a capacity that it will be possible to distribute all the goods taken from one ship berthed opposite to it.

When goods are handled by hand, the average height of tiering or piling averages about five feet. It is, therefore, evident that there would be required a very large floor area to distribute and place a cargo of 6000 tons according to the marks and cross marks, especially if a miscellaneous cargo.

Assuming 60 cubic feet, instead of the marine 40 cubic feet, to represent the volume of one ton and 15% more for distributing space, this would equal about seventy cubic feet per ton. Six thousand tons would, therefore, represent a cubical content of 420,000 cubic feet, and, at an average height of five feet, would cover a space of 84,000 square feet.

As the average freight ship, not passenger liner, is about 500 feet in length, and the length of the shed should correspond to the length of the ship, this would mean a building 500 feet in length and 168 feet in width for this tonnage.

The reason for the five-foot height for average tiering is that manual lifting above this height means a considerable increase in the handling expense. It is more economical to hand-truck 400 feet than to lift ten feet by man-power. By mechanical tiering, freight can be tiered 20 or even 30 feet with little, if any, additional expense over tiering five feet.

Assuming an average height of tiering at 15 feet, a building could be made 56 feet in width, 500 feet in length, and yet have a capacity on the above basis, of 6000 tons, at 70 cubic feet per ton. In order to allow even more floor space for the distributing, or a greater holding-shed capacity, 20 feet may be taken as an average tiering height. A shed, therefore, 60 feet wide, 500 feet long and with a clear height below the girders of 30 feet, tiering 20 feet, would accommodate 8500 tons, allowing 70 cubic feet per ton. This, or a shed 400 feet in length, would be a properly proportioned shed for inland river terminals.

It is interesting to note that 60 feet is the standard width of inbound railway freight stations.

For larger freighters at ocean terminals, the length per berth could be increased to 600 feet and the width of shed to 80 feet, giving a holding capacity of about 13,700 tons.

If the width of the sheds can be kept within the above limits, the cost of the shed will be less than is usual, as there will be one short span only and no intermediate posts to interfere with the freight movements, which posts should be avoided if possible.

It is evident that capacity is secured by height and not by width, and that the floor space inside the shed should not be occupied by railroad tracks nor used as a dray area. In general, the railway tracks should be in front of and behind the sheds and not in the sheds.

The functions of the shed are chiefly for assorting, distributing, tiering and temporary holding for 48 to 72 hours. The mechanical appliances should occupy no floor space for this tiering, or for the assorting and distributing.

Warehouse Functions.

The function of the warehouse is to relieve the shed of cargoes which are not removed within the 48 to 72 hours. Each shed should have its accompanying warehouse, to prevent congestion in the shed. A cargo may remain in storage in the warehouse as long as the storage rates are paid. From the warehouse, goods will be transferred to drays, cars, sheds, and often to ships, barges or lighters for re-shipment. As there are railway tracks between the shed and the warehouse and as the

tracks are depressed, the full-arch gantry can transfer goods directly between the warehouse and drays or railway cars.

The following diagrams, plan and the elevation B. B., make plain the above description as pertaining to quay terminals. The three photographs, 1, 2 and 3, are of an installation similar in design and plan.

No. 1 shows the quay, the railway tracks, the traveling gantry jib-crane and the front of the one-story shed.

No. 2 shows the rear of the shed, tracks, cranes, and the front of the four-story warehouse.

No. 3, also, shows the shed tracks, cranes, and the warehouse more in detail.

On a projecting pier, both sides of the pier shed would be the same in design as the left side of the shed and quay in elevation B. B. If the pier should be 150 ft. in width, there would be the 35 ft. between the pier wall and the shed, with tracks and cranes in this space; the shed, 80 ft. in width, with its assorting, distributing and tiering machinery; then a 35-ft. space between the shed and the pier wall at the other side of the pier, with its tracks and cranes.

Transference between the pier-shed and the quay-shed and warehouse is by the overhead fixed and movable tracks and small motor-trucks.

It can be asserted that combinations of the traveling gantry jib-cranes, the ship's winch, the overhead traveling hoists in trains, and the movable tracks and the electrical motor-truck fulfill all the exacting conditions of the transferring and handling of miscellaneous cargoes or package freight. There are attained great flexibility and a large range of operations, eliminating delays, congestion, and reducing the employment of unskilled manual labor to the minimum, and with a continual succession of movements. There is a great variation in the cost and speed of cargo transference and handling, due to different kinds of cargoes and favorable or unfavorable conditions; but with a correctly designed terminal, using the mechanical appliances as described, manual labor costs can be reduced by one half, and the time of loading and discharging also by one half.

The nearer any system is universal in its operations, the more satisfactory will be the results.

Various Types of Shore Appliances.

In the place of the gantry jib-crane, the transporter or the cantilever gantry-crane can be substituted, and in some cases, to great advantage; but on account of the single or double gantry jib-crane being able to serve some one hundred feet of lineal water frontage without any traveling movement, and the facility with which, combined with the overhead traveling hoists, burtoning can be effected, preference is generally given to the gantry jib type.

The Gantry Jib-Crane Specifications.

The following are a few of the general specifications for such cranes.

The half-arch or semi-portal crane, has a horizontal limb of from 35 to 50 feet spanning two or three tracks elevated 17 to 25 feet above the rails, with a jib of a length of 50 feet and a radius of 35 to 50 feet. It is capable of lifting two tons at a speed of three to four feet per second; or three tons, or even more, at a proportionally less speed. The slewing is from 7 to 10 feet per second, or 2½ swings per minute. The traveling speed is about 70 feet per minute. There is a slow speed motor for each movement, preferably a direct-current motor. The characteristics of these cranes are the quick movements of lifting, rotating, lowering, starting, and positive braking. The controlling cab is placed within the jib members, so that the operator may obtain an unobstructed view of the complete hoisting operations.

Traveling-Hoist Trains.

These trains consist of one tractor, or the conveying mechanism, and three or four electric hoists drawn after the tractor. All are controlled by one transferman. The speed of the train is 750 feet per minute with a six- to eight-ton load.

Each of the hoists has a lifting capacity of two tons at 60 to 80 feet per minute, or three tons at less speed. Two traveling hoists combined can give a lifting capacity of four to six tons. The connection between the movable cross or loop track and the fixed track is by means of gliding bridges.

The number of traveling hoists is proportioned to the number and capacity of the gantry cranes, so that in burtoning from the hooks of the gantry cranes to the hooks of these traveling

hoists there is no delay or congestion, either of the cranes or hoists.

There are given views of tractors, traveling hoists and gliders.

Other Hoisting and Conveying Appliances.

There are many types of hoisting and conveying appliances installed at marine terminals, but these as a rule, are designed for special commodities and not for universal application. It is possible only to enumerate the more important.

Portable electric dock winches, with 20-horsepower motors
Stationary, electric dock winches, with 18-horsepower motors
Floating steam hoisters
Floating grain elevators
Whip hoists
Traveling unloaders, 5 to 10 tons capacity
Elevated stationary hoisting winches
Pillar-cranes
Locomotive-cranes
Stationary bridge-cranes
Lifting towers and belt conveyers
Derrick booms and grab-buckets
Coal dumps on tipples
Barrel conveyers and elevators
Gravity chutes and conveyers
Bag and box chutes
Baggage escalators
Cargo chutes
Blind-hatch hoists
Stationary cranes, hammer type, of great capacity.

Bulk Material Cargoes.

As an example of one of the latest and best coal-handling plants of large capacity, reference is made to the installation at Panama for the United States Government.

Coal Handling Plant for the Panama Canal.

The Panama Canal has contracted for a coal-handling plant and the contracts embrace designing, fabrication, delivery, and erection at Cristobal and Balboa. These will consist of

2 Duplex stocking and reclaiming bridges

6 Reloaders
2 Conveying systems
2 Wharf bunkers
6 Unloader towers
The cost is $1,833,129.00.

The unloaders at Cristobal have a capacity of 1200 tons per hour, and the bridge diggers and reloaders 1200 tons per hour. This plant is for both the storing and reclaiming coals, and for a more complete description reference is made to the bibliography.

Ore and Coal.

The following views of bulk-cargo, transferring machinery indicate what a high degree of efficiency, in economy and speed, has been attained in the discharging of the ore- and coal-carrying ships. The data and figures, as to discharging, make this clear without further explanation.

In loading the ships, taking Duluth as an example, the ore is brought from the mines in cars, each holding about 50 tons, and is dumped through bottom doors into the ore-dock packets, taking often only 15 seconds per car. From the pockets, the ore runs by gravity through many hatches into the hold. A vessel can be loaded with 12,000 tons of ore in an hour.

For unloading cars of coal into the ships, the most efficient method consists in raising the car filled with coal and, by inverting, dumping into the vessel. These car dumps have a capacity of 900 tons, or even more, per hour.

For transferring sand, gravel and a smaller coal tonnage, jib-cranes of various types and bridge transporters are installed. These have a capacity of 60 to 100 tons per hour for this smaller service.

Belt Conveyers.

For the handling of phosphate rock, moving belts to the ship's side are used at some of the Atlantic Coast terminals. Traveling and stationary cranes and the ship's winch are used for the secondary movement of loading.

CONCLUSIONS.

First. That on the ship there should be at least two double winches for each hatchway, and sufficient booms for bur-

toning the load, simultaneously, either upon the shore or lighters.

Second. That upon the quay or piers there should be traveling gantry jib-cranes, one for each one hundred feet of lineal frontage, spanning two or three railway tracks, which tracks are located between the shed and the quay wall.

Third. That within the shed there should be overhead movable cross tracks connecting with fixed side tracks, so as to assort and distribute the freight and to serve every cubic foot of space (tiering) by a continual succession of movements, without rehandling and not using floor space; and, also, so as to afford a short path across the shed from the vessel on one side of the pier to another vessel on the other side.

Fourth. That the freight should be moved without congestion or delay, by burtoning between the hooks of the gantry cranes or of the ship's winches and the hooks of the traveling hoists.

Fifth. That freight should be transferred between the shed and any floor of a warehouse by one direct movement of the gantry cranes.

Sixth. That to secure the greatest rapidity and economy in the above freight movements, the design of the ship and the plan and layout of the elements of terminals should receive careful study.

Seventh. That for bulk material, the mechanism should be able to reclaim as well as store, and to distribute at a considerable distance from the quay walls.

Eighth. That to obtain the greatest return from investments in ships and terminals, the latest mechanical appliances should be installed for speed and economy of transference and handling.

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1. "The Black Diamond", Chicago, Dec. 12, 1914.

2. "Progress in Marine Construction", Proceedings, Institution of Civil Engineers, Vol. CXCIV.

3. House of Representatives Document, No. 226, 63d Congress.

4. House of Representatives Document, No. 857, 63d Congress.

APPENDIX.

Diagram I. Plan of an Inland Terminal showing the relative position of the ship, the quay, the tracks, the shed and the warehouse, with the transferring cranes and the overhead handling and tiering machinery; also open storage spaces for special commodities and bulk material.

Diagram II. Sectional elevation of the Inland Terminal, indicating the quay wall, the half-arch gantry-crane, the railway tracks, the shed with the overhead fixed and movable tracks, the full-arch gantry-crane, the cars and the warehouse.

Diagram III. General plan of the Kirby Point Project at Beaumont, Texas.

Fig. 1. The river, the quay, the tracks, the cranes and the front view of the shed.

Fig. 2. Rear view of the shed, the tracks, the cranes and the warehouse.

Fig. 3. A more detailed view, especially of the warehouse.

Fig. 4. An enlarged view of a ''Brownhoist'' full-arch gantry-crane, depicting the hoisting, derricking, slewing and traveling devices.

Fig. 5a. One type of tractor and traveling-hoist used for assorting, distributing and tiering, either within or without the sheds. The conveying and hoisting can be performed simultaneously by the operator.

Fig. 5b. The tractor and carriage-hoist passing from the fixed side-track to the movable cross-track by means of the glider. By the movable cross-tracks every cubic foot of space can be served rapidly and by a continual succession of movements, without rehandling by manual labor.

Fig. 6. Five overhead traveling hoists, handling sugar between the vessel, shed and the warehouse, of the American Sugar Refining Company, New Orleans, La. The waterway is at the right of the photograph. The motors are of the enclosed direct current type, with a travel speed, with one-ton load, of 1000 feet per minute and a hoisting speed of about 100 feet per minute. Electric and foot brakes are applied. There is a lineal berthing frontage of 850 feet. The distance of travel varies from 2000 to 3000 feet. There are 25 cars, each car conveying about 15 tons per hour, including high tiering. Manufactured by the Shepard Electric Crane and Hoist Company, New York.

Fig. 7. Four 17½-ton electric ore-unloaders for handling bulk material on the dock of the Pennsylvania Lines, west of Pittsburgh, Cleveland, O. The bucket capacity of these machines is the largest thus far constructed. The labor cost for unloading a cargo of ore, including cleaning up, is about 0.012. In regard to unloading speed the following is the report of unloading at Ashtabula on August 20, 1913:

4 machines started work at 6:30 A. M., finished work at 10:30 A. M.; gross time, four hours; tonnage removed, 10,762. Manufactured by the Wellman Seaver Morgan Co., Cleveland, Ohio.

Fig. 8. ''Brownhoist'' freight-handling installation for the New York Dock Co., Baltic Terminal, Brooklyn, N. Y. The trolleys are shown at the freight house end. The system extends from here over five lines of freight car tracks, through warehouse and to dock in front of warehouse. The trolleys are designed to handle miscellaneous package freight on special four-wheel trucks, or heavy lifts in sling loads.

Fig. 9. ''Brownhoist'' fast plant unloaders. Pittsburg & Conneaut Dock Co., Conneaut, Ohio. Crane equipped with man-trolley and Brown patent 5-ton ore grab-bucket. Capacity 350 to 400 tons of ore per hour.

Figs. 10a and 10b. Unloading plant of West Bay Lumber Co., in Florida; shows the method and equipment used for unloading lumber from vessel to dock.

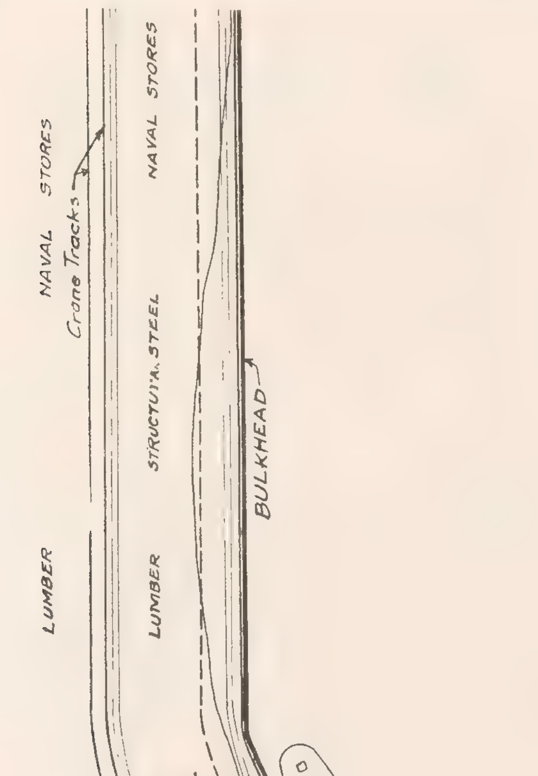
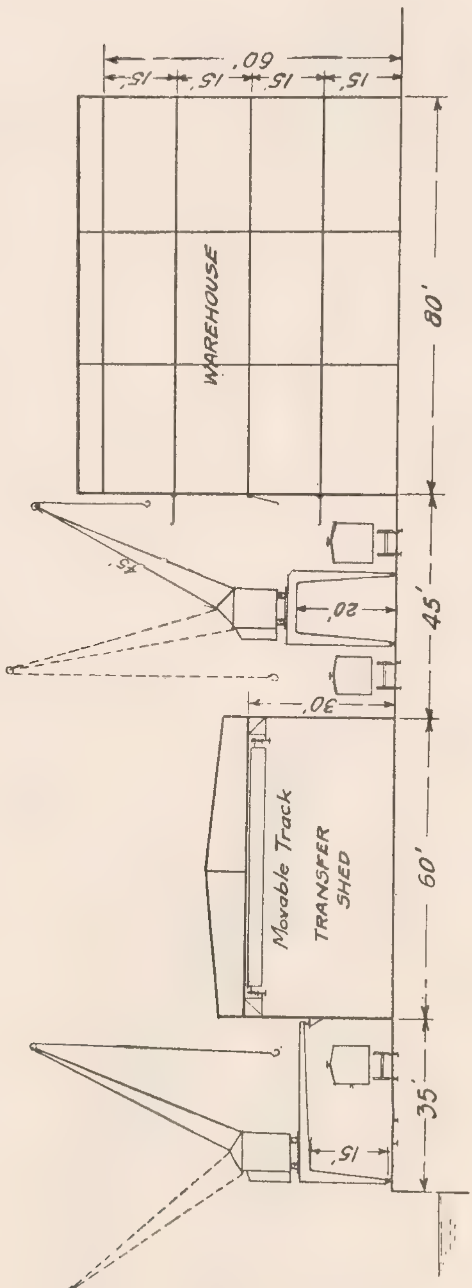
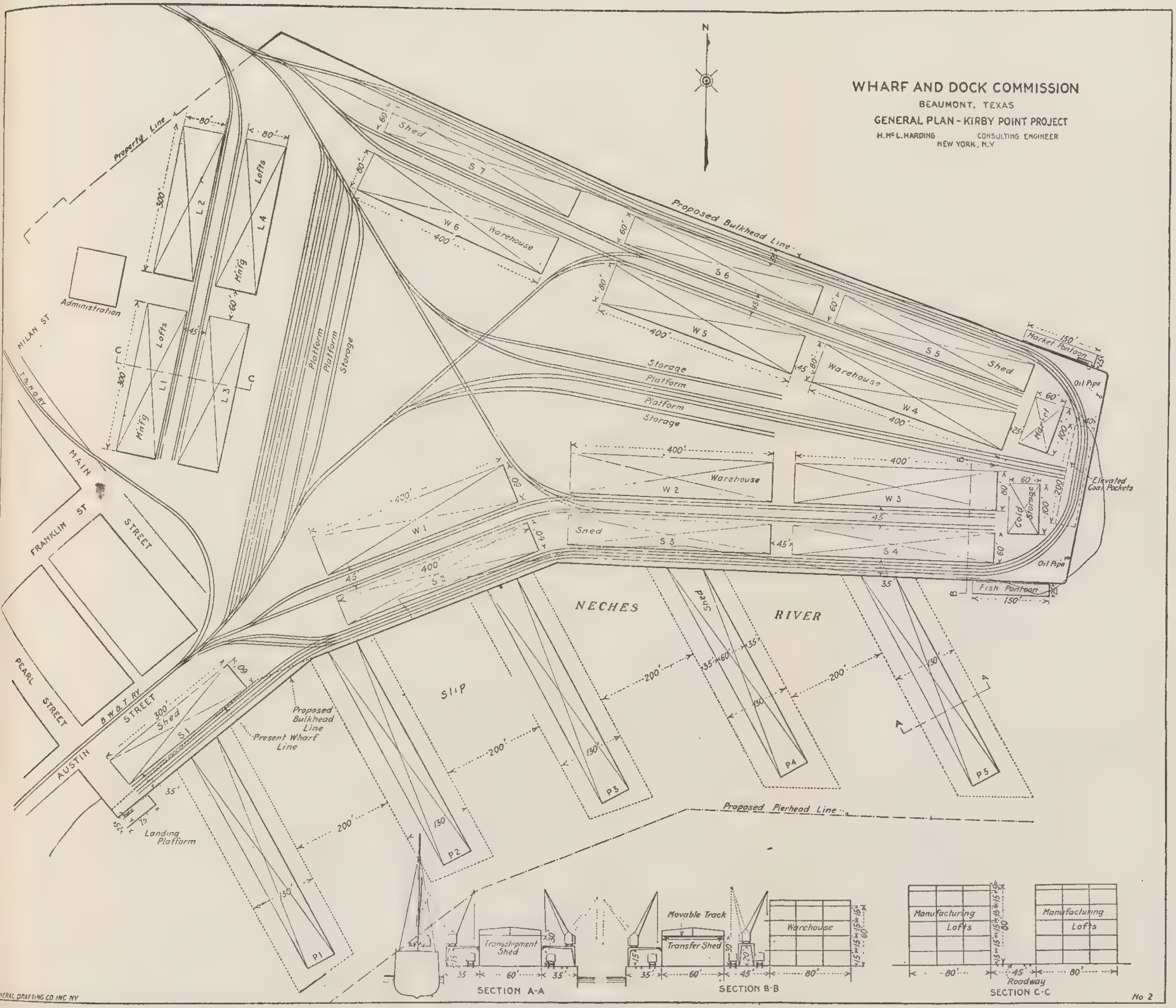

NAVAL STORES
Crane Tracks
NAVAL STORES
LUMBER
STRUCTURAL STEEL
LUMBER
BULKHEAD
80'
60'
Movable Track
B
B
WAREHOUSE W 1
400'
SHED S2
Crane

Diagram I.



SECTION B-B
Scale 1 inch = 25 ft.

Diagram II.



WHARF AND DOCK COMMISSION
BEAUMONT, TEXAS
GENERAL PLAN - KIRBY POINT PROJECT
H. McL. HARDING CONSULTING ENGINEER NEW YORK, N.Y.
Proposed Bulkhead Line
NECHES RIVER
SLIP
Proposed Pierhead Line
Property Line
Administration
MILAN ST
MAIN STREET
FRANKLIN ST
PEARL STREET
AUSTIN STREET
Landing Platform
Present Wharf Line
Market Pontoon
Fish Pontoon
Elevated Coal Pockets
Oil Pipe
Cold Storage
SECTION A-A
SECTION B-B
SECTION C-C
Transshipment Shed
Transfer Shed
Movable Track
Warehouse
Manufacturing Lofts
Roadway
No 2

Diagram III.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

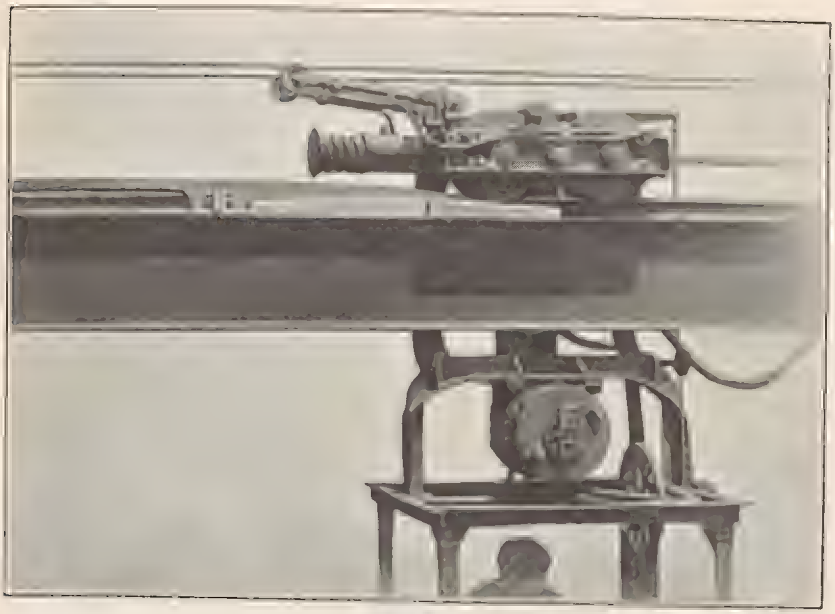


Fig. 5a.

Fig. 5b.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10a.

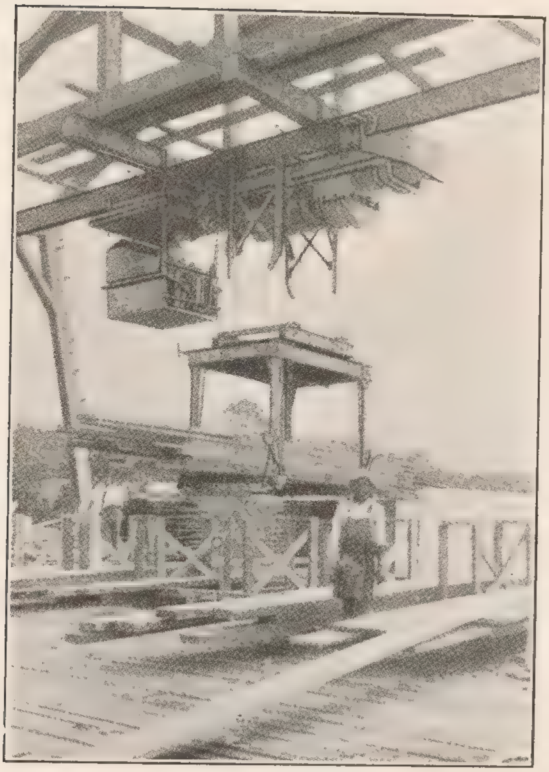


Fig. 10b.

DISCUSSION

Mr. Lopez.

Mr. J. V. Lopez‡ said that the new municipal dock of the city of Los Angeles is 1,800 ft. long and 100 ft. wide. The clearance from the side of the shed to the pier line is only 6 ft. Masts spaced 20 ft. apart support a steel I-beam running the full length of the shed. Shed doors are 22 ft. high and 17 ft. wide. A continuous fender log is placed about 1½ ft. above the door. The cargo winches are inside the shed, close to doors.

A cargo line is run from the winch through a block hung from the I-beam and thence into the hold through a block on a breastline. The load is lifted from the hold to about 10 ft. above the deck of the wharf. The breastline is then slacked away and the load allowed to swing through the door. The line strikes the fender log and the load is dropped inside the shed. By this means cargo is handled with the least possible trouble and placed in a convenient position for transportation to different points in the shed.

Mr. Meigs.

Mr. John Meigs,§ M. Am. Soc. C. E., wrote that to a casual student of the subject, American steamship piers, except those especially equipped for the handling of cargoes of very special nature, look crude as far as the mechanical equipment is concerned, and our freight-handling apparatus seems primitive and ineffective. Whether this apparent ineffectiveness of equipment is actually true of our best piers, as compared with the best European installations, he thought open to reasonable doubt. It might be granted that European engineers have not spent the enormous sums necessary to install the extensive batteries of expensive dock cranes, which are so common in their ports, without at least, what they have considered, good and sufficient reasons.

He said that European conditions and American conditions with reference to the loading and discharging of ships at piers are different in some essential respects, particularly as to the customary position of the railroad tracks on the piers, the type of freight cars in common use, etc., and doubtless this difference in pier-design practice has, to some extent, determined the policy of our steamship terminal operators as to the type of mechanical freight-handling equipment adopted.

For the mere transference of freight from the ship to the pier deck, there to be distributed by hand-truck, he questioned whether a crane of any type is more efficient either in speed of operation or economy of cost than the double-whip system of handling cargo, which is in very general use in this country, provided these whips are operated by steam or electric hoists of good design and ample size, which is not always the case. He thought the author's designation of this method as the "burtoning" of cargo, a convenient one, that it would be well to adopt for general use. He had been informed, on fairly reliable authority, that the discharging of vessels at some of the American terminals of European steamship lines is done at a less cost by this method than the same

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vessels are loaded and discharged at the European terminals of the same companies, at which dock cranes are used instead of the burton tackle. Notwithstanding all of the literature which has been published concerning the wonderful performances of European dock cranes, he had not yet seen any actual figures for cargo handling with them that demonstrate conclusively their superiority over the simple burtoning method. He was, therefore, not yet convinced that the adoption of dock cranes on American piers would be a step in advance. Mr. Meigs.

Mr. Meigs stated that the magnificent mechanical equipment of European ports that we hear so much about, and for the lack of which we are continually held up to scorn by European critics, is confined almost exclusively to the handling of cargo at the ship's side—from the ship to cars alongside of it or to the pier deck—and does not extend to the further distribution of cargo in the pier sheds, which latter really is the most tedious and expensive part of the operation of cargo handling, and by long odds the most difficult part to perform satisfactorily.

Of many suggested solutions of the problem of interior distribution, he said that some are excellently adapted to special classes of cargo and have been successfully operated, but none of them, applicable to general conditions, has been tried out on a sufficiently large scale to form any definite conclusion regarding its success. The excellent suggestions of the author in this line seemed feasible, and at least worthy of a careful trial. He believed in the possibility of developing a successful telpher system, success implying not only mechanical adequacy, but also economy of handling. In the consideration of the element of economy, however, we should not stop at the mere stevedoring costs, but must give due weight to the very large additional pier value created by the telpher, owing to the possibility, under its use, of utilizing two or three times the vertical height of pier space that is now possible with any truck system, either hand or mechanical, operating on the pier deck. Even if the actual stevedoring cost of cargo handling should not be decreased by use of the telpher, the much needed storage space gained by it would represent a tremendous financial advantage. Piers are expensive investments and any means by which the utilizable space on them can be radically increased would represent money saved. The element of time required for loading or discharging vessels, must also be taken into consideration, and if a vessel, worth on time charter from $500 to $1,000 per day, could be loaded or discharged one day quicker, by the use of a mechanical interior distribution system, than by present methods, this saving would pay not only additional stevedoring charges, but the interest on a considerable amount of money investment in the necessary mechanical equipment.

Mr. Meigs said that many eminently successful types of apparatus have been devised and are widely used for handling special cargo. But the problem of the distribution of general cargo in pier sheds is a complex one, and up to the present time, so far as he was informed, there had been no successful large-scale installations of any such apparatus

Mr. Meigs. in this or any other country. A thorough trial of either an improved telpher system, or the "overhead movable cross-track system" advocated by the author, by some pioneer with both the money and courage to make the installation, would be awaited with great interest.

He held that one very good reason why more attention had not been devoted to the practical solution of this problem of interior distribution, has been the diversity of interests involved in the interior handling of freight. Frequently the marine carrier's responsibility for the cargo ends with its deposit on the pier deck. After being so deposited on the pier, if it is intended for local delivery, the consignee usually calls with his own dray and collects it from the deck where it has been left by the steamship. If it is destined for trans-shipment into the interior, usually the railroads load it into their cars from the pier deck at their own expense. Sometimes still other interests are involved. Frequently the pier owner is neither the steamship company, the railroad, nor a consignee or consignor of large amounts of freight. If so, he feels that he can probably derive as much rent for his pier without a mechanical transfer system in it as he could with it, and is, therefore, disinclined to invest the money that would be required for an adequate mechanical equipment.

No one of these participants in cargo movement is sufficiently interested individually to justify, in his mind, the expenditure of any large amount of his own money for the installation of cargo transfer equipment, particularly as he feels that if his competitors are subjected to the same annoyance and expense in handling freight that he is, he is just as well off as they are. For these reasons it is extremely difficult to secure the necessary funds for making an initial installation to demonstrate whether it would be economically successful.

Mr. Meigs described certain improvements in apparatus for handling cargo to and from ships' holds recently designed for Philadelphia without changing the burtoning principle. It appeared desirable to improve the type of hoist used for performing this operation. To this end, there were recently designed and built several dock winches involving one novel principle of construction: the hoists are of the double-drum type, electrically operated, and are provided with a system of remote control. By means of this, the operator, with a small portable controller suspended from his shoulders and connected to the hoists with a flexible electric cable, can stand on the ship's deck alongside of the hatch which is being worked, and see and direct the movement of loads from the time they are hooked onto in the hold until they are landed on the pier deck. Under the ordinary system of burtoning, there are two whips in operation—one operated by a winch located on the deck of the ship in proximity to the hatch opening, but not near enough for the operator to see down into the ship's hold; the other whip is controlled by another winch, either located, as the first one is, on the ship's deck, or otherwise on the pier deck. The winchman, having but a poor view of the packages, has

to be guided by a signalman,—two operators and a signalman being required to handle each load. Mr. Meigs.

The improved remote-control hoist places in the hands of one operator the control of both whips of the burton tackle and dispenses with the services of one winch-operator, at least one signalman, and possibly two (as occasionally a signalman is provided for each winch), and increases the speed of handling the loads.

These hoists are only just completed and have not had an actual trial in service, but the mechanical obstacles in the way of operation have been overcome, and a considerable economy is fully expected in this item of expense in connection with cargo transfer from piers to vessels and from vessels to piers.

Mr. H. McL. Harding, in closing the discussion, says that in the paper presented by the writer, the following may be said to be the principal recommendations: Mr. Harding.

> First.—For all ports of the United States, and especially for those concerned with foreign commerce, those operating methods and mechanical appliances should be adopted which have proved most efficient in respect to time and economy of cargo transference and handling.
>
> Second.—That all new terminals, for inland and ocean navigation, should be so designed, planned and proportioned in respect to the piers, quays, sheds, warehouses and railway tracks, as to secure easy, quick and economical intercoordination between all these terminal elements and with the water carriers.
>
> Third.—That not only should the world's best without prejudice be adopted and then adapted to the operating conditions in the United States, but American terminal engineers should continually study to achieve something better.

It is shown in the paper, by data and figures from Federal Government reports, that there is a lack of speed and economy at most of the ports of the United States, many of which use dock winches and other similar appliances as recommended by Messrs. Meigs and Lopez. Dock winches for many purposes are excellent; but as recommended for package freight, the following quotation from a public document, the printed report of the Directors of the Port of Boston for the year ending November 30, 1914, page 25, may be of instructive interest:

> "Twenty-four electric winches, rotary converter and power wiring, for use in transferring cargo between ship and pier were purchased, although no agreements were made for any charges for the same. These winches were purchased on or before December, 1913, and had not been used up to the end of the fiscal year 1914, being stored on the pier. The total cost of these winches, together with the wiring, is $114,209.05, and the annual carrying charge of these winches, which would appear on the books of any properly conducted private enterprise, including interest, repair and replacement, based on a life of fifteen years, is $13,419.23."

Mr. Harding.

The above for the Cunard and Hamburg-American Lines is not intended in any way as a criticism of dock winches but of the special adaptation of such devices for miscellaneous cargoes.

Similarly, winches on an elevated platform, Pier 48, North River, Southern Pacific Co., are seldom used.

The great disadvantage of such winches is the congestion point at the place of deposition, generally at the shed door, which congestion prevents continuous speed.

Paper No. 218

CARGO HANDLING METHODS AND APPLIANCES.

By

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INTRODUCTION.

To one who has not made a special study of the subject of this paper, it may seem relatively narrow and unimportant; therefore, the first part of the paper will attempt to show briefly the magnitude of the subject and its vital importance, not only to those directly interested, but to the public at large. Past and present methods of cargo handling, with brief outlines of machinery used, will then be taken up, bringing out, in particular, the inefficiency of our present system. Future trend of freight handling methods with suggestions for improving the situation will then be covered, and the paper will be concluded with a brief reference to the available forms of power for operating freight handling machinery.

WORLD'S COMMERCE.

Cargo results from commerce; hence, a few statistics on the world's commerce will emphasize the importance of considering cargo handling more seriously than hitherto. The value of imports in thirty-one principal countries of the world for 1912 was nearly nineteen billion dollars and exports during the same time amounted to nearly seventeen billion dollars. The United States' share of the 1912 imports and exports was nearly four billion dollars, and it is increasing at a rate of nearly 10% per year. Converting these values into tons, by dividing by the average cost per ton obtained from data on twenty important exports and imports, we find a tonnage of approximately one billion (907,-

200,000 metric tons), for the world's commerce, and over a hundred million for the share of the United States. At thirty-five cents per ton (907.2 kg.), the average cost for actual handling of freight, the cost of loading and unloading the world's commerce in each terminal, is three hundred and fifty million dollars, and of this the United States pays about one tenth.

Commerce is an interchange of the products of our natural resources in their raw, semi-finished and finished stages; therefore, the high cost of this interchange falls directly on the producers of the raw material and on the manufacturers who change the raw to a semi-finished or finished material. Finally, however, this charge falls on the ultimate consumer, the public, who, grudgingly, pays the bill and kicks about the high cost of living. How much of the high cost of living is directly attributable to the high cost of handling the world's commerce is hard to estimate, but it undoubtedly plays a large part.

Little can be expected in further reducing the cost of actually transporting freight, as improvements in this direction have received world-wide attention; therefore, we must look to the terminals for our next field for improvement, and here we find unlimited possibilities.

CLASSIFICATION OF FREIGHT.

In general, freight can be classified into three main divisions, viz., bulk freight, live freight, and miscellaneous or package freight.

Bulk freight consists of free-flowing material, such as coal, ore, grain, certain fertilizers, etc., which can be transported and handled in bulk. The classification of bulk freight can be carried only two steps, viz., kind of material and weight; and this simplicity has been a large factor in the development of the rapid means now used for handling such freight.

Live freight requires such special consideration during transportation and in loading and unloading that it is probably being taken care of as economically and rapidly as possible at the present time. Therefore, nothing more will be said about it in this paper.

Miscellaneous or package freight presents the most serious problem, as it forms the greater part of all freight, both in

weight and bulk. The varying size, shape, strength and weight of packages make its classification an endless task; a single cargo often containing 50 to 100 thousand packages; divided into hundreds of different sizes, shapes and weights, and consigned to several hundred different parties. The transportation companies have an elaborate system of classifying this package freight to determine the freight charges, but such a classification would be of little value so far as handling is concerned. A classification based on size, weight and shape would be the logical way of attacking the problem.

PAST METHODS OF FREIGHT HANDLING.

The history of the handling of bulk or free-flowing freight makes interesting reading, and there is probably no better place to follow it out than on our own Great Lakes, where the development of rapid, economical handling has been carried to a very high degree.

In the early days, any kind of boat willing to take a bulk cargo was used, and loading and unloading were accomplished, largely, by men with wheelbarrows. As business increased, keen competition arose and the hand methods became too slow and too expensive. This condition spurred on the designers of boats, piers and handling machinery, with the result that specially designed bulk-freight boats began to appear; grain elevators, coal and ore piers, etc., arranged to load the boats from spouts, were built; steam-operated cable-type bridges replaced the wheelbarrows for unloading, thereby causing a revolution in the handling of bulk freight. Development along these same lines, with perhaps some radical improvements in unloading machinery, have continued unabated, until Lake boats now carry cargoes of 12,000 to 13,000 tons (10,880 to 11,800 metric tons), which, in some instances, have been loaded at a maximum rate of over 22,000 tons (20,000 metric tons) per hour, and unloaded at the rate of over 2,000 tons (1815 metric tons) per hour. The cost per ton (907.2 kg.) has been reduced from somewhere around \$3.00 to about \$.07, and the time saved is enormous.

Past methods of handling package freight, with few exceptions, are the same as present methods. The quality of the

units employed has remained stationary, while the quantity has increased, to keep pace with trade.

On the levees of the Mississippi, today, an inclined plane is run from the deck to the top of the levee and negro roustabouts carry much of the freight out on their backs, and we can hardly imagine the galleys of the ancients being unloaded by a more primitive method. Soon after the advent of steam for power, the steam winch was invented to supersede the hand- or animal-operated windlass then used to empty and fill the holds; and altho that occurred early in the last century, the steam winch still performs the largest part of the work.

The flexible hand truck, which has done yeoman service in the past, still handles by far the largest part of our cargo; the only change that has come with our increasing freight traffic has been the addition of more hand trucks. The date of the first hand truck seems to be obscure, but it is more than probable that, in some form or other, it has been used for several centuries.

Unit loads and speed of movement in the past were no doubt less, on an average, than at the present time, but what little improvement has taken place has been insignificant compared with the enormous increase in the volume of our commerce. Within very recent years, a few mechanical devices have been used for freight handling, but their adoption has been so recent that they will be covered under the next heading.

PRESENT METHODS OF CARGO HANDLING.

Bulk freight, by virtue of its free-flowing nature, lends itself very readily to mechanical handling, and, as pointed out previously, machinery for handling it has been developed to a high degree of efficiency. It is beyond the scope of this paper to go into a detailed description of this apparatus, so only a broad view of some of the general types of machinery will be given.

The boats designed for this service, particularly on our Great Lakes, deserve special mention. Machinery and living quarters are crowded fore and aft, leaving the center free for freight. This central space is so designed, structurally, that it is entirely free from stanchions, bulkheads or obstructions of

any kind—in other words, it is one immense bin, offering the greatest amount of freedom for the huge unloading buckets to pick up their load. The deck contains a continuous line of hatches, close enough together so that the jaws of a clean-up bucket will span from one hatch to the next, thus doing away with the necessity for hand shovelling.

Ocean-going bulk freighters have been given the same special consideration with regard to maximum carrying capacity and special adaptation to the use of loading and unloading machinery. While their design is somewhat different from the Lake boats, the same requirements are met. In each case, ease of loading and unloading and capacity are given first consideration.

Bulk-freight loading and unloading equipment varies according to the kind of material handled and the conditions to be met. For loading vessels, where storage facilities are desired as well, a typical arrangement consists of the bin-type pier. This consists of a pier entirely covered with storage bins. Railroad cars are run to the top of the bins and dumped directly into them. Numerous hinged spouts lead from the bottom of the bins to the hatches of boats lying alongside, and the material flows by gravity from the bins to the boats. Where storage facilities are not required, car dumpers represent an efficient type of loading apparatus. With this apparatus, gondola type freight cars are hoisted to the required height and turned over bodily, thus dumping their entire contents into a chute leading to the vessel's hatch. In other cases, where conditions justify it, continuous bucket or belt conveyors are used, which deliver material from stock bins to the vessels.

In general, the unloading of bulk freight is taken care of today by bridges, stiff-leg unloaders, towers, conveyors and combinations of the above devices. The first three of these devices use self-digging, self-dumping buckets of various capacities.

Bridges are of two general designs—the man trolley type, where the operator rides with the trolley and bucket, and the rope-operated type, where the operator and the machinery are stationary and the bucket travels across the bridge by a cable. Both accomplish the same purpose, which is to unload the boat and deliver the material to either the stock pile, railway cars,

transfer cars or weighing larries. Buckets, with capacities of from ten to fifteen tons, are in use, which will handle a bucket load in a minute to a minute and a half, depending on where the load is being dumped. One bridge is in operation at a port on the Great Lakes, which has a maximum unloading capacity of 880 (800 metric tons) tons of coal per hour when dumping about 150 feet (44.2 meters) back from the boat.

Perhaps the most radical departure in unloading machinery came with the introduction of the stiff-leg pantograph unloader, generally known as the Hulett Unloader, and it makes an excellent example of what inventive genius and boldness will do under stress of pressure. These unloaders are built in the shape of a huge pantograph mounted on a track. The lower end of one of the vertical arms carries the bucket and the operator's cab so that the operator travels with his bucket and can work to the best advantage. On picking up a bucket of ore in the hold of the vessel, the bucket is raised, after which the entire pantograph travels backwards on tracks until the bucket is over a hopper, into which it is dumped. From the hopper, the ore goes to a weighing larry, and thence to the stock pile or a railroad car. The largest of these unloaders has a 15-ton capacity (13.6 metric tons) bucket, and a complete cycle of operation takes about one minute. By actual weight, the 15-ton bucket has picked up 21 tons (19.05 metric tons) at one grab. The capacity of the machine, under favorable circumstances, is somewhere around 900 tons (817 metric tons) per hour. The design of the bucket is such that it is very efficient in cleaning up material in the bottom of boats, thus doing away with hand shovelling.

Tower-type unloaders are usually used where great rapidity is necessary; they simply hoist the material out of the boat and dump it into a hopper with the shortest possible trip. Conveyors are generally used to take the material from the hopper to the storage pile. On account of the high speed, which, on some towers, is 30 seconds per round trip, the buckets are of moderate capacity, ranging from one to two and a half tons.

Conveyors are most generally used in connection with some of the above unloaders, except in handling grain, and in some special cases where conveyors load and unload directly in the boat.

Miscellaneous or package freight, in direct contrast to bulk freight, is surrounded by conditions which make mechanical handling rather difficult. This is, no doubt, largely responsible for the lack of machinery in the business. Steam-driven ship's winches and hand trucks still load and unload practically all of the freight in this country; and the only improvement, if it can be called such, made abroad has been the use of wharf gantry-cranes. The very size of these wharf cranes makes their use questionable, for, while capable of greater loads, it is doubtful if the average loads handled by them are greater than the loads handled by ship's winches, while the time required to make a complete cycle is certainly longer than that required by the light winch. With the present design of vessels, the hatch is the neck of the bottle, and the rapidity of unloading should depend upon the number of trips that can be made thru the hatch. This maximum speed is, however, seldom obtained, as, with both ship's winches and dock cranes, the loads are not only brought thru the hatches, but they are swung across deck and onto the wharves, thus losing time making the long return trip. If the load were deposited at the mouth of the hatch, the empty return trip would be short and more freight would come thru the neck of the bottle. Conveyors could take the load from the mouth of the hatch to the wharf shed. This system has been used at one municipal dock with good success.

Lack of landing space on wharves is a great handicap to rapidity, with the ship's-winch method of cargo handling, and to some extent, with the wharf crane. A gang of truckmen will never operate with the regularity of the ship's winch, with the result that there are periods when the winches are held up for lack of truckmen, and other periods when truckmen are bunched at the landing space waiting to load their trucks. Wherever the human element has to enter into cargo movements, there should be some reservoir capacity provided between different freight movements, if maximum efficiency is to be attained.

There are a few piers, both here and abroad, on which some up-to-date machinery is in use; but there is not a single case known where a complete mechanical equipment handles all freight. This is largely due to the design of existing piers and vessels being such that mechanical devices can not be used to

best advantage, and partly because of the aversion of stevedores and labor unions to the use of machinery. The machinery used consists of winches, conveyors, storage-battery trucks and truck cranes, monorail or telpher systems, elevators, escalators, ramps, cranes of various types, and gravity chutes of various designs. Most of these devices have proven their worth and have shown a reduction in time and cost for handling cargo.

FUTURE TREND.

Broadly speaking, the future trend is toward more machinery for cargo handling. Three important steps must be covered in order to bring about the adoption of machinery:—First, the educating of steamboat companies, stevedores and labor unions to see its advantage; second, the design of vessels and piers to be especially adaptable to the use of machinery; third, a systematic, scientific study of freight and freight movements.

The educational movement can probably be best carried out by the various naval and marine technical societies and the various machinery manufacturers thru the medium of magazines, the press, papers to be read at society meetings, and advertising literature.

Reference to the design of vessels and piers will be made further along.

It is rather difficult to determine on whom the study of freight and freight movements would legitimately fall. It would seem reasonable to expect large ports to take it up as a municipal problem; as commerce always follows the line of least resistance, and anything done to increase port facilities raises the prestige of the port, and a greater flow of trade thereto follows. Consulting engineers specializing on terminal work might study this phase of the subject to great advantage, perhaps assisted financially by the transportation companies and manufacturers of machinery. It might even be of sufficient importance to justify an investigation by a commission of engineers and transportation experts appointed and paid by the national government. An investigation of this kind would include a time and cost study of all freight movements from the hold of a ship to the warehouse or car, and vice versa. This

would determine where loss of time occurs and would definitely locate the cause of the high cost. It would also include a study of the size, shape and weight of packages, and the methods of boxing, crating and packing.

From the data thus obtained, such problems as the most adaptable types of machinery; the most efficient design of piers and vessels; the standardizing of the size, shape or weight of packages, and the methods of packing; the most efficient utilization of labor, etc., could be far more satisfactorily solved.

SUGGESTIONS FOR IMPROVING CARGO HANDLING METHODS.

The complete mechanizing of such an immense, cumbersome business as cargo handling must necessarily take time, study and expense. Cooperation and system are essential, in order to reduce these factors to a minimum. At present, the few interested parties seem to be working along different lines, as individuals. These facts have been kept in mind by the writer in making the following suggestions:—

1 The appointing of committees on mechanical cargo handling by the various interested engineering, architectural, naval and marine societies.

Such committees could do much educational work which would stimulate interest by encouraging papers on the subject, to be presented before the societies. Such papers would lead to investigations, tests and a closer study of actual conditions.

2 A committee of naval architects to study the design of ships, with special reference to rapid loading and unloading of cargo.

The improvement in the design of bulk freight vessels would indicate that much could be done to improve vessels for miscellaneous freight, if given due consideration. A radical change in design may be in order, as indicated by one vessel recently launched, and one completely designed by a naval architect on the Pacific Coast but not built. The vessel launched is a bulk freighter with a complete self-contained conveyor-type unloader, which completely unloads the entire cargo, with no manual labor, and deposits it on a stock pile on shore. The second vessel is equally well adapted to bulk or package freight. Her freight is loaded into barges, which are floated into the

boat thru hinged gates in her bow, after which the gates are closed and the water is pumped from her ballast tanks until the barges rest on sills in her hold.*

3 A committee of pier and wharf engineers to study the design of piers especially adaptable to the use of machinery. Existing piers are poorly adapted to the use of machinery, and, strange as it may seem, such points as ratio of length of dock space to pier capacity, in square or cubic feet, seem to have been given very little consideration. Some piers lately built have berth space for ten ten-thousand-ton ships, and a floor space capable of holding about one and one-half ships' cargoes. Machinery might make a two- or three-story pier feasible and economical.

4 The possibility of using wet docks, where tidal conditions are bad. Wet docks, with the help of ballast tanks and pumps aboard ships, would hold a vessel at a constant height, regardless of tide or load, and under this stability, some type of conveyor might be used from the hold to the pier. A conveyor is the ideal machine, as it keeps freight flowing in a stream, with no abrupt changes in handling, and its speed can be so adjusted that it is actually a reservoir in itself, which prevents freight from piling up.

5 An investigation of the situation by municipal, state and national governments. Governmental departments already exist which should consider such investigations their legitimate duty, on account of the vital interest of the public at large in this problem. Port cities should strive to make their municipally-owned piers the acme of perfection, thus setting an example which private corporations would soon follow.

Time, money and energy will be required to carry out the above suggestions, while existing conditions demand immediate action; therefore, the following suggestions are made with the view of relieving the immediate situation:—

(1) The use of electrically-operated portable winches, controlled by portable controllers and driven by power from the pier. The advantages of this scheme are:— (a) Constant source of power, as it would be entirely independent of the ship's

* Railway and Marine News, December, 1914, for complete description with drawings.

boilers; (b) portable controller makes load visible to operator at all times—this prevents loss of time and the danger of signaling; (c) the winchman gets familiar with his equipment, instead of having to get accustomed to a different winch with each ship; (d) winches being owned by the stevedores, could be kept in first class condition. Ship's winches are often in bad repair and time is lost making them operate satisfactorily.

(2) Use of electrically-driven portable conveyors and stackers, for unloading, distributing and piling where conditions permit.

(3) The use of storage-battery operated trucks, truck cranes and tractors for distribution of cargo.

(4) The efficient lighting of piers, wharves and docks.

(5) The employment of trained engineers to supervise and direct the handling of freight.

POWER FOR CARGO HANDLING MACHINERY.

Just as electricity has superseded all other forms of power in all large industries, so will it be universally adopted for cargo handling machinery. Ship's boilers or donkey boilers should not be depended on for cargo handling machinery, as they have not proved reliable. Central station electric power is available in all port cities and is sufficiently reliable to meet the requirements demanded of it by dock machinery.

Direct current seems ideal for this service, as control and wiring problems are much simpler and more satisfactory than with alternating current. However, alternating current can be used satisfactorily, if necessary. With either D. C. or A. C., the most desirable voltage is from 220 to 250, from the standpoint of safety and insulation.

CONCLUSION.

Education along broad lines is of vital importance and must reach from the capitalist down to the dock laborer. Complete familiarity with existing conditions and methods, and the factors affecting them, is essential. A more general recognition of the importance of the subject by governments, technical societies and manufacturers, and a close cooperation between them, is necessary in order to get quick and beneficial results. The

complete adoption of electrically-driven machinery, wherever conditions justify mechanical devices, is needed.

Numerous interesting articles have appeared in the technical press in recent years, which can best be located thru the Engineering Index, issued yearly.

Much information on this subject can be obtained from reports made to the authorities of New York, Boston and other large cities having water terminals; also, from certain House Documents, U. S. Congress.

Paper No. 219

SOME ECONOMIC FUNDAMENTALS OF FREIGHT HANDLING.

By

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The activities of the economic world consist, in general, of the production and consumption of economic goods and the transportation of these from the producer to the consumer. These activities may be classified as the production, transportation, manufacture, distribution and consumption of commodities.

The fundamental activities of life are supposed to be in connection with the individual's struggle for existence and for the reproduction of his kind. As civilization develops, the barrier between necessities and luxuries is ever shifting, the luxuries of yesterday being the necessities of today. Food, shelter and clothing are far from supplying the demands of present existence.

Raw materials are but seldom consumed in their original form; therefore, the manufacturing industry. Raw materials are found in the ocean, forests, mines, the soil, and the atmosphere. Their location is apparently in part due to accidents of nature and to certain peculiar favorable conditions of temperature, rainfall, etc.

The raw materials of the ocean are the food products, such as fish and the various forms of sea food, skins from seals, oil from whales; vegetable products, such as kelp and sponges; and minerals, such as the various salts.

From the birds and animals of the forest we obtain food and clothing. From the forests themselves we obtain material

for construction, fuel and paper. Mines and quarries give us fuels, metals, structural materials and a large miscellaneous assortment. From the few inches of fertile soil which cover the surface of the earth we receive the large food supply which supports the present civilization, and which consists of a wide variety of animal and vegetable life, many of the direct and by-products of which are used for clothing.

Localities for production are limited, while consumption may be over entirely unrelated areas and may cover much larger percentages of the earth's population. For example, the use of cotton, tobacco, sugar, tea and coffee, wheat, rice, etc., is very general throughout the civilized world. The places in which these can be grown are limited by natural climatic and geographic conditions; and in transporting these raw materials from the place of production to the place of consumption, often through localities in which they are used for the manufacture of some other product, we have the activity of transportation, in which is involved the subject of Freight Handling.

In the transportation of goods, a large number of domestic animals is employed, as well as manual labor and carts and vehicles of various forms. By far the largest part of the transportation of commodities in the more civilized countries is, however, now done by either rail or water. From the producer to the consumer, the goods must usually be handled many times in changing from one vehicle of transportation to another; and herein is involved a large part of the expense which the ultimate consumer finally pays for his commodities.

In any economic activity in which the supply and demand vary in value at different times, the function of storage is necessary. In the transportation of commodities, storage plays an important part. We have the seasonal storage, in warehouses, such as with coffee, wheat, cotton, etc.; we have the storage associated with transportation, found in grain elevators, freight houses, wharves, docks, etc.; we have the storage connected with manufacture, and also the storage involved in the wholesale and retail distribution; as well as storage, such as coal, flour, sugar, etc., on the premises of the consumer.

These storage facilities equalize the uneven flow of commodities from production to consumption, and it is in connec-

tion with the transfer and storage facilities that there is employed a large proportion of the work of freight handling. It is here that the field exists, at the present time largely undeveloped, for the employment of power-operated mechanical devices.

The most fundamental necessity in the world, as previously mentioned, is food, and after that comes clothing and shelter and a large number of demands that once were luxuries and now are considered necessities.

In connection with the every-day activities, some of the necessary commodities of life are given in Table 1, and the first and second place in production of the principal staples of the world are listed in Table 2.

TABLE 1.

Some of the Necessary Commodities of Life.

Food:

Barley, butter, cocoa, coffee, corn, eggs, fish, fruit, meat, milk, oats, potatoes, rice, rye, salt, spices, sugar, tea, wheat, etc.

Construction:

Aluminum, copper, gold, iron, lead, silver, tin, zinc, cement, glass, stone, etc.

Fuels:

Coal, oil, gas, wood.

Clothing:

Cotton, fur, hemp, leather, silk, wool, etc.

Miscellaneous:

Chemicals, explosives, ink, paper, seeds, tobacco, wines, etc.

TABLE 2.

First and Second Place in Production of Staples.

Corn	United States	Argentina
Wheat	Russia	United States
Rye	Russia	Germany
Oats	Russia	United States
Rice	China	British India
Sugar	Germany	Cuba

Tea	China	British India
Coffee	Brazil	Venezuela
Cocoa	Gold Coast	Ecuador
Tobacco	United States	British India
Cotton	United States	British India
Wool	Australia	Argentina
Silk	China	Japan
Coal	United States	Great Britain
Petroleum	United States	Russia
Pig Iron	United States	Germany
Steel	United States	Germany
Copper	United States	Japan
Tin	Malay States	Bolivia
Gold	Transvaal	United States
Silver	Mexico	United States

This table also indicates what are considered ''staples''.

Data regarding the figures associated with world-wide conditions are not always obtainable, so that the requirements of the average individual, as given in Table 3, are confined to American conditions:

TABLE 3.

Individual Requirements.

The Average American—

Requires Imports	\$19 per year.
Exports	\$23 per year.
Is responsible for	\$42 in commerce.
Requires the hauling of 18 tons of freight 150 miles.	
Has in his pocket	\$34.53.
Consumes	85 pounds of sugar.
Uses	30 pounds of cotton.
Uses	6 pounds of tobacco.
Uses	23 gallons of liquors.
Uses	10 pounds of tea and coffee.
Owns wealth	\$1400.
Can stand alone in a 20-acre plot.	

The world figures for population and production are given in Table 4:

TABLE 4.

World Figures for Population and Production.

Total land area of world	57,641,102 sq. mi.
Total population of world	1,732,000,000.
Average density	30 per square mile.
Greatest density—Europe	121 per square mile.
Least density—South America	5.2 per square mile.
Density of United States 1910 } 30 years	32 per square mile.
Density of United States 1880 } 30 years	16.9 per square mile.
Fertile regions of earth	50% of total.
White (civilized)	775,000,000.
Yellow, brown, black, red	957,000,000.
Average duration of life	33 years.

25% die before 6 years.
50% die before 16 years.
99% die before 65 years.

World's Products.

Fisheries	$ 493,000,000
Cotton	1,050,000,000
Sugar	720,000,000
Wheat	2,647,000,000
Coal	1,804,000,000

The natural products of the earth, ocean and air are very largely transformed before being consumed, and this brings about a large field of human activity known as manufacturing. The principal raw materials and their general products are given in Table 5.

TABLE 5.

Raw Materials, Sources and Products.

- Animal
  - Meats
    - Packing-house products
    - Prepared meats
    - Fish meats
    - Poultry and eggs
    - Fertilizers
  - Hides
    - Hair, fabrics, hats, felt
    - Fur
    - Leather
      - Belting
      - Shoes
      - Harnesses
  - Fertilizers
  - Oils
    - Greases
    - Lard oil
    - Tallow
    - Lard

- Sea
  - Fish
    - Fresh
    - Preserved
    - Canned
    - By-products
    - Fertilizer
  - Vegetable
    - Sea weed, chemicals, fibres
    - Foods
  - Animal
    - Furs
    - Oils
    - Foods
    - Shells
    - Coral
    - Sponges
- Forest
  - Logs
    - Lumber
      - Furniture
      - Building parts
      - Containers
      - Boats
    - Timber
    - Shingles
    - Lath
    - Ties
    - Poles
    - Paper
    - Veneer
    - Fertilizer
  - Fuel
    - Firewood
    - Charcoal
  - Chemicals
    - Gums
    - Oils
    - Dyes
    - Drugs
    - Sugar
- Farm
  - Grains
    - Flour
      - Bakery products
      - Prepared foods
    - Feed
    - Liquors—Alcohol
    - Beers
  - Fodder
  - Fruits
    - Canned
    - Natural
    - Expressed
  - Vegetables
    - Canned
    - Natural
    - Prepared foods
      - Bulk
      - Package
        - Manufactured products
  - Fibres
    - Wool
    - Cotton
    - Flax
      - Fabrics
      - Yarns
      - Cordage
      - Thread
        - Bedding
        - Clothing
        - Sails
        - Floor coverings
        - Draperies
    - Silk
    - Thread
      - Fabric
- Mines
  - Coal
    - Hard
    - Soft
  - Ores
    - Pig metals
    - Metal Shapes
      - Castings
      - Fabrications
      - Machinery
      - Tools
      - Containers
    - Chemicals
  - Chemicals
    - Fertilizers
    - Manufactured products
    - Drugs
    - Pigments

- Quarries
  - Stone
    - Slate
    - Marble
    - Granite
    - Building Stone
      - Cut stone
      - Slabs
      - Monuments
      - Roofing
  - Banks
    - Clay
    - Gravel
    - Sand
    - Broken stone
      - Bricks
      - Cement
      - Lime
      - Abrasives

- Wells
  - Oil
    - Oil products
    - By-products
      - Fuels
      - Lubricating
      - Paint
  - Waters
    - Table waters
    - Salt
    - Chemicals
    - Medical waters
  - Gas
    - Fuel
    - Illumination

One of the principal problems of commerce and of freight handling has to do with the wide variety of form and density of the packages in which these various commodities are transported; and the difficulty of properly adapting power-operated mechanical devices to the field of freight handling is due, in considerable part, to this diversity in the character of the packages to be handled. This is illustrated in Table 6.

TABLE 6.

Weight and Density of Freight.

- Weights of units 10 lbs. to 75 tons
  - Spices, Supply Parts, Groceries—10 to 100 lbs.
  - Liquids—100 to 3200 lbs. (Cocoanut Oil)
  - Fibres and Textiles—250 to 800 lbs.
  - Machines—10 lbs. to 75 tons.
  - Staples—100 to 400 lbs. (Sugar, Coffee, Rice, etc.)
  - Timber—185 lbs. (Ties) to 13 tons (Mahogany).

- **Density**
  - Greatest—Pig Copper, Pig Lead.
  - Least—Palm Leaf Fans, Millinery, Drums, Bird Cages.
  - Exports and Imports—40 cu. ft. per ton—50 lbs. cu. ft.
  - L. C. L. Transfer Freight—12.7 lbs. cu. ft.
  - G. E. Manufactures 22 lbs. cu. ft.—9 tons per car.

Freight, in general, is divided into a number of classes as shown in Table 7.

TABLE 7.

Classification of Freight.

Freight	Bulk	Free Flowing	Oil, Sand, Grain, Coal, Ore
		Non-Flowing	Brick, Coke, Pig metals, Lumber, Steel
	Live Stock	Horses, Cattle, Sheep, Hogs, Poultry	
	Package	Boxes, Barrels, Bags, Crates, Bales, Bundles, Articles, Machinery	

In connection with the handling of bulk freight, many efficient mechanical devices have been developed and the cost of such handling enormously reduced from the original elemental way, as illustrated by the present means of handling coal, grain and ore. In the handling of package freight, the difficulties are much greater and the development very much less advanced. Package freight is shipped in a large variety of containers, as illustrated in Tables 8 and 9.

TABLE 8.

Containers for Package Freight.

Containers	Crates	Machinery, Fruit
	Hampers	Vegetable
	Boxes	Wood, Veneer, Fibre board, Metal
	Barrels	Slack, Tight, Wood, Steel
	Drums	Steel
	Bags	Cotton, Jute
	Wrappers	Jute, Paper, Burlap, Cotton

TABLE 9.

Size of Freight Goods.

Size:
- Smallest—Net Bulk—Bricks, Pig Metals, Spices, Parts.
- Largest—Dredges, Locomotives, Cables, Water-wheels, Machinery.
- Most Convenient—Soap Boxes and Coffee Bags.
- Best Space Factor—Fibre Board Boxes.
- Least Desirable—Explosives.

Freight may be defined as material en route from the producer to the consumer, through the manufacturer and distributing agencies, as given below in Table 10.

TABLE 10.

Freight.

Freight is material en route.

From place where first produced, to
- Consumer.
- Processor, consumer.
- Processor, manufacturer, consumer.
- Processor, manufacturer, jobber, retailer, consumer.

Oceans or continents, or both, may intervene at any point in the above.

As for instance:

Calf skins, Russia—processed New York.
Manufactured—Massachusetts.
Wholesaled—San Francisco.
Retailed—Alaska.

The facts regarding railroad and marine freight as applying to American conditions are shown in Tables 11 and 12.

TABLE 11.

Freight Traffic of United States.

Number of freight cars	2,300,000
Average haul	143 miles
Total mileage of freight cars	19,466,000,000
Total ton miles of freight	264,000,000,000
Miles of road	245,000
Freight locomotives	38,000
Switching locomotives	10,000
Total railroad mileage of world	640,000

TABLE 12.

Average Density of Marine Freight, 40 Cu. Ft./Ton.

United States

Steam	14,822	Average gross tonnage	365
Sail	6,100	Average gross tonnage	230
Canal Boats	700	Average gross tonnage	70
Barges	4,293	Average gross tonnage	230

Total value of merchant marine under American flag (June 30, 1914) $507,973,121

Value per gross ton $70

(Gross tons of ship is entire volume in cubic feet divided by 100. Net tons remain after deducting engine, boiler, bunker and crew spaces. Dead weight carrying capacity is two and one-half times net tons.)

Total gross tonnage of ships of world 48,157,000
16½% under American Flag.

Increase in tonnage of principal maritime nations in last ten years:

American	22½%	German	40%
British	18%	Dutch	48%
French	23½%	Belgian	97%
Norwegian	33⅓%	Italian	36%
Swedish	34%	Austro-Hungary	75%
Danish	20%	Greek	66%

The economic and engineering problems of freight handling have to do with the cost and efficiency of the means employed, and especially, at the present time, of the possibilities of increasing capacities of present installations. Figures regarding the cost of transporting freight are given in Table 13, and some figures regarding the cost of handling freight at transfer points in Table 14.

TABLE 13.

Average Cost Per Ton Mile.

Earth roads, animal power	25 cents
Steam railroads	7.8 mills
Canals	2 to 3 mills
Rivers and sounds	1 mill
Lakes and ocean	½ mill

TABLE 14.

Some Typical Costs of Terminal Freight Handling.

Hand trucking 200 feet	8c	per ton
Loading drays (actual time only)	5½c	per ton
Loading box cars (18 cars—average 25.5 tons)	12c	per ton
Unloading box cars (20 cars—average 21.5 tons)	11½c	per ton
Loading offshore ships (41 ships—package freight)	22.8c	per ton
Discharging offshore ships (28 ships—package frt.)	20c	per ton

The carriers of freight may be divided as in Table 15, with regard to the handling of goods by individual producers and consumers.

Public carriers are classified in Table 16.

TABLE 15.

Carriers of Freight.

- Carriers
  - Animal
    - Man
    - Dog
    - Horse
    - Water buffalo
    - Ox
    - Camel
    - Elephant
    - Llama
    - Mule
    - Donkey
  - Vehicle
    - Hand
      - Wheelbarrow
      - Sled
      - Hand truck
      - Cart
    - Animal Propelled
      - Wagon
      - Sleigh
      - Sledge
      - Cart
      - Tote poles
    - Power
      - Electric truck
      - Trailers with tractor
      - Steam truck
      - Gas truck
      - Trolley car
      - Freight car
  - Boat
    - Row boat
    - Canoe
    - Sail boat
    - Ship
    - Tow barge
    - Steam barge
    - Steam boat
    - Steam ship

TABLE 16.

Public Carriers.

- Public Carriers
  - Marine
    - Deep-sea
      - Steam ships
      - Sail ships
    - Coast-wise
      - Steam ships
      - Sail ships
      - Tow barges
    - Lake
      - Steam ships
      - Tow barges
    - Canal
      - Steam barges
      - Tow barges
    - River
      - Steam barges
      - Tow barges
    - Harbor
      - Lighters
        - Bulk
        - Package
        - Car
  - Land
    - Electric surface roads
    - Electric subways
    - Railroads
      - Gondola
        - Hopper bottom
        - Solid bottom
      - Flat
      - Box
        - Refrigerator
        - Stock
        - Grain
        - Special
      - Tank
      - Special
    - Trucks
      - Electric
      - Steam
      - Gas
    - Drays

When the bulk of freight is broken in passing from water to land, or vice versa, and at different points on land, special devices suited to localities and conditions are used, as illustrated in Table 17.

TABLE 17.

Freight-Handling Apparatus.

- Freight-Handling Apparatus
  - Gravity devices
    - Spiral tube
    - Rollers in series
    - Smooth chute with risers
  - Endless conveyors
    - Smooth belt trough
    - Wood-slab moving platform
    - Bucket chain
    - Scraper chain
  - Track devices
    - Electric monorail cars and trailers
    - Storage battery locos. and cars
    - Trolley locomotives and cars
    - Cable roads
    - Hand cars
  - Trackless devices
    - Hand trucks
    - Battery-truck cranes
    - Power trucks
      - Gas
      - Electric
      - Steam
  - Cranes
    - Fixed derricks
    - Movable derricks
    - Girder cranes (Shop Type)
    - Hammerhead cranes
    - Locomotive cranes
    - Fixed and movable trolley-bridges.

One of the biggest problems of freight handling is to adapt the design of the terminals, cars, ships, carriers, and warehouses to the character of the goods handled and the conditions under which they must be moved. A typical ship's cargo is given in Table 18, and an example of the cargo of a freight car in Table 19.

TABLE 18.

Typical Ship's Manifest.

1,327 cases Curios	2,409 bags Tea Sweepings
756 cases Bristles	5,980 bags Copra
17 cases Hats	500 bales Cassia
33 cases Human Hair	3,325 bales Hemp
109 cases Horse Tails	171 bales Strawbraid
10 cases Ess Oil	116 bales Sheepskins
2 cases Portiers	1,389 bales Wool
10 cases Tobacco	199 bales Bamboo
3 cases Medicine	35 bales Goatskins
64 cases Albumen	27 bales Goatskin Rugs
15 cases Rhubarb	87 bales Hats
500 cases Antimony	168 bales Cotton
140 cases Canned Crabs	85 casks Ginger
135 cases Crackers	3,222 casks wood and nut oil
25,728 cases Tea	2,391 rolls matting
14 cases Effects	17,828 pieces Copper
7 cases Preserved Ginger	103,978 mats Sugar
731 cases Groceries	14 empty Cylinders

It took 300 men ten days to unload the above cargo from the ship, which had a stand-by charge of $300 per day.

TABLE 19.

Typical L. C. L. Freight Car.

The following is a summary of the Bills of Lading for N.Y.N.H.&H. Car No. 74048 from Utica to Schenectady, received May 12, 1915.

Where items are duplicates they are separate shipments, either to different parties or from different places.

1 bbl. Liquid Paint	1 box Brass Cocks
5 bbl. Pretzels	5 bags Iron Castings
20 boxes Clothes Pins	1 box Brass Goods
11 cases Matches	2 boxes Brass Goods

20 cases Pork and Beans
1 Fireless Cooker
2 boxes Glue
1 bbl. Hardware
2 cases Candy
1 keg Pipe Fittings
1 crate Picture Frames
3 boxes Household Goods
1 box Pipe Fittings
2 boxes Electrical Appliances
1 case Brass Fittings
10 bundles Brooms
1 Side Car
1 Motor Cycle
1 Motor Cycle
1 box Tin Plates
1 Motor Cycle

Examples of the paths followed by commodities from the producer to the consumer in the cases of paper and coffee are given in the following:

Paper: Wood pulp floated down streams to freight terminal; freighted to paper mill; processed into paper; freighted to news office; freighted (as in case of Saturday Evening Post) to distributing centers; collected, baled and freighted to collection centers; freighted to paper mills; processed for box stock; freighted flat to box factory; freighted knocked-down to consumer, etc.

Coffee: Drawn to railway terminals; freighted to port; put in warehouse; shipped over seas to United States; freighted from storehouse to inland processor; repacked and shipped to wholesaler; again shipped to retailer.

Under present conditions, the great problems of freight handling have to do largely with terminals, and a classification of these is given in Table 20.

TABLE 20.

Classification of Freight Terminals.

- Terminals
  - Railroad
    - Local station
      - Incoming freight
      - Outgoing freight
    - Branch intersection
      - Incoming freight
      - Outgoing freight
      - Transfer freight
    - Junction of two roads
      - Transfer to foreign roads
    - Transfer station
      - General transfer between many roads
  - Marine with railroad connections
    - General
      - Incoming freight
      - Outgoing freight
      - Transfer freight
      - Marine
        - Local
        - Foreign
    - Municipal ownership
    - Railroad ownership
    - Corporate ownership
      - Storage
      - Transfer
      - Manufacturing
    - Navigation company ownership

In Curves No. 1 to No. 10, which are self-explanatory, are given some statistics of the commerce of the United States and the world, and the illustrations accompanying this paper will serve to indicate some of the activities and possibilities in the field of freight handling.

CONCLUSION.

The subject of transportation and distribution of commodities is, from an economic and engineering standpoint, one of the most important at the present time. A scientific time motion, detailed study of the operations is beginning to be made. It is a field in which generalities are not applicable, and in which scientific facts are necessary for proper solution of the problems involved.

The immediate problems have to do with the installation of mechanical apparatus in present terminals and for use with present ships, cars and warehouses. The design of apparatus for this purpose and the modification of present devices to render them suitable for this work has only begun.

The development of ports and harbors, the location of docks, terminals and warehouses, the design of the same and of the ships and freight cars, the design and application of proper devices for handling the goods, and attempted standardization of package sizes—these are some of the problems involved.

Amongst other standpoints, the field offers attractive possibilities for central-station power loads and is one which will be developed in the near future.

The great economic saving which will come from improved efficiencies in systems of transportation, and in the design of accompanying features, has quantitative possibilities of the utmost importance.

The general outline of the factors involved has been given in this paper from an economic as well as from an engineering standpoint, and their proper solution will be obtained by following scientific methods of investigation, analysis and construction.

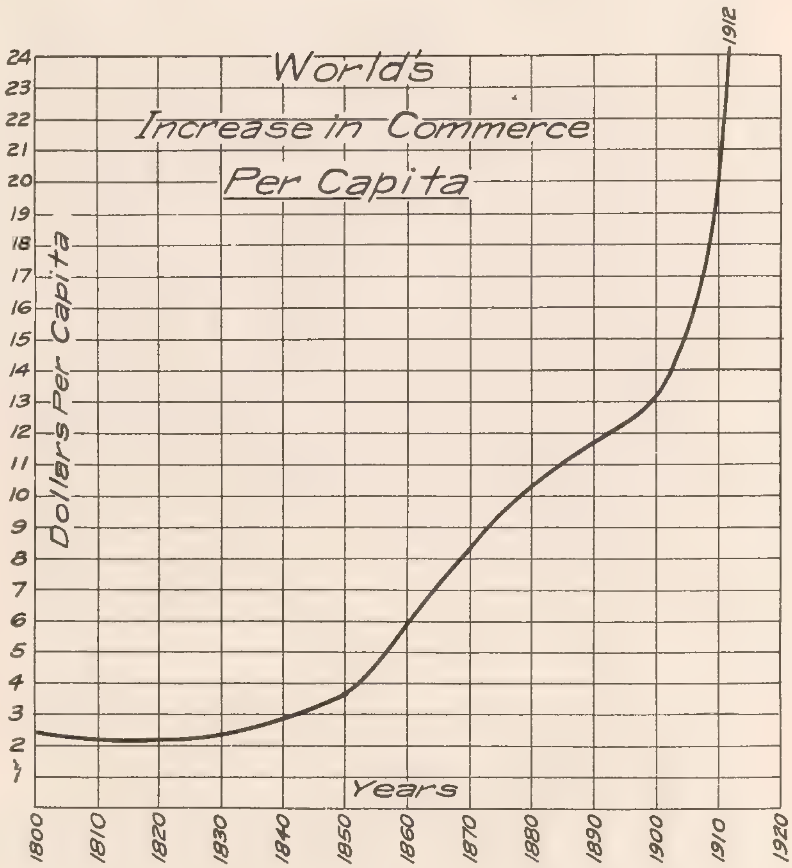
World's
Increase in Commerce
Per Capita
Dollars Per Capita
Years
1912
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920

Fig. 1.

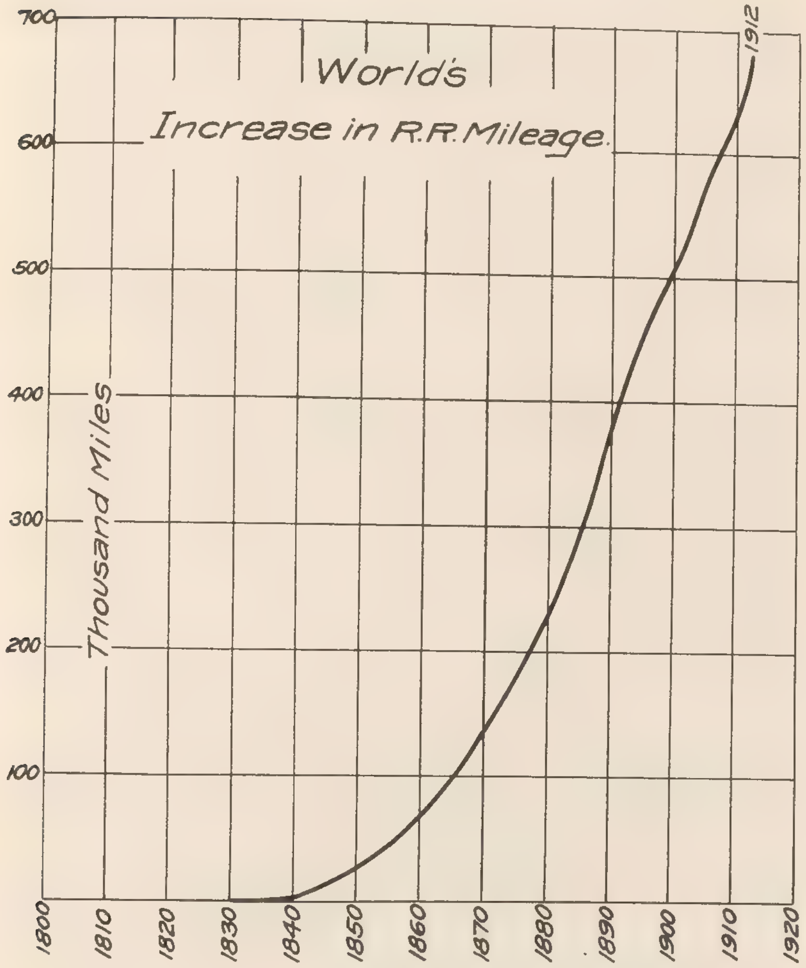
World's
Increase in R.R. Mileage.
Thousand Miles
700
600
500
400
300
200
100
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1912

Fig. 2.

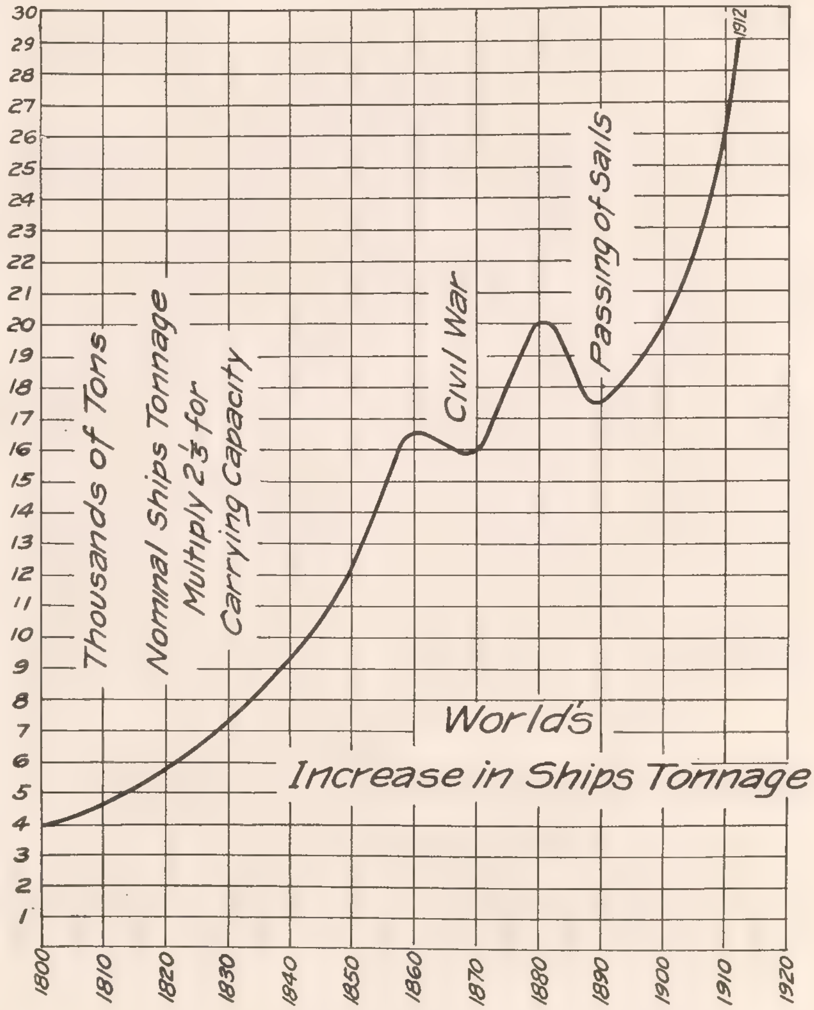
Thousands of Tons
Nominal Ships Tonnage
Multiply 2⅓ for
Carrying Capacity
Civil War
Passing of Sails
World's
Increase in Ships Tonnage
1912
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920

Fig. 3.

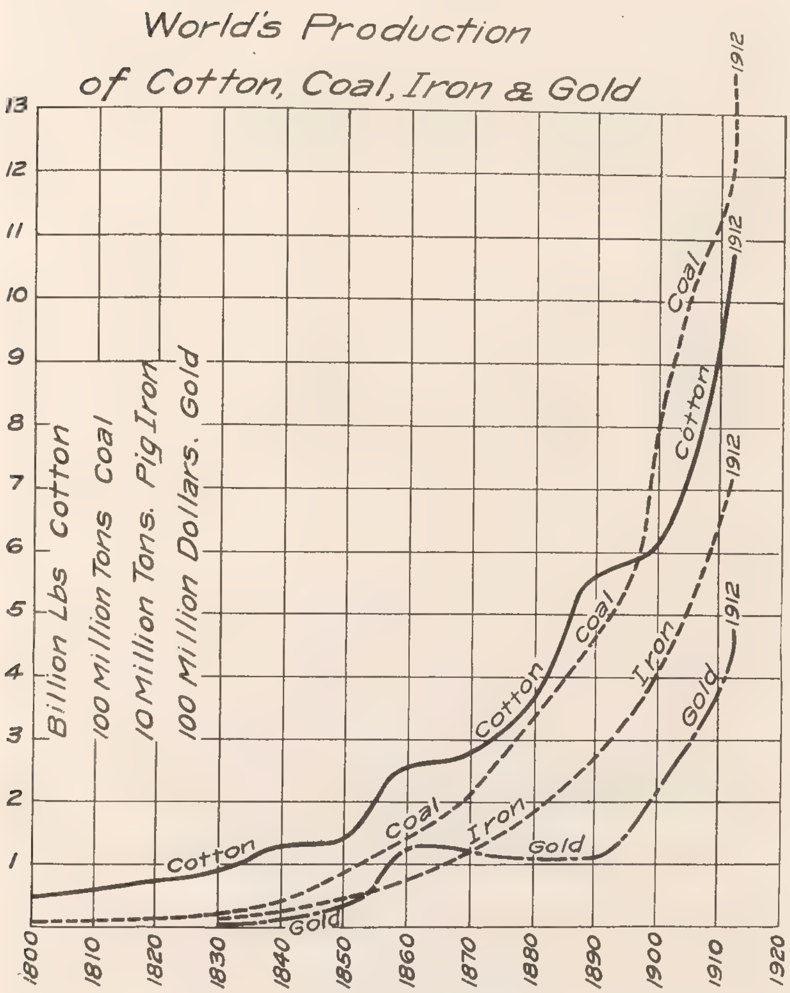
World's Production
of Cotton, Coal, Iron & Gold
Billion Lbs Cotton
100 Million Tons Coal
10 Million Tons. Pig Iron
100 Million Dollars. Gold
Cotton
Coal
Iron
Gold
1912
1
2
3
4
5
6
7
8
9
10
11
12
13
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920

Fig. 4.

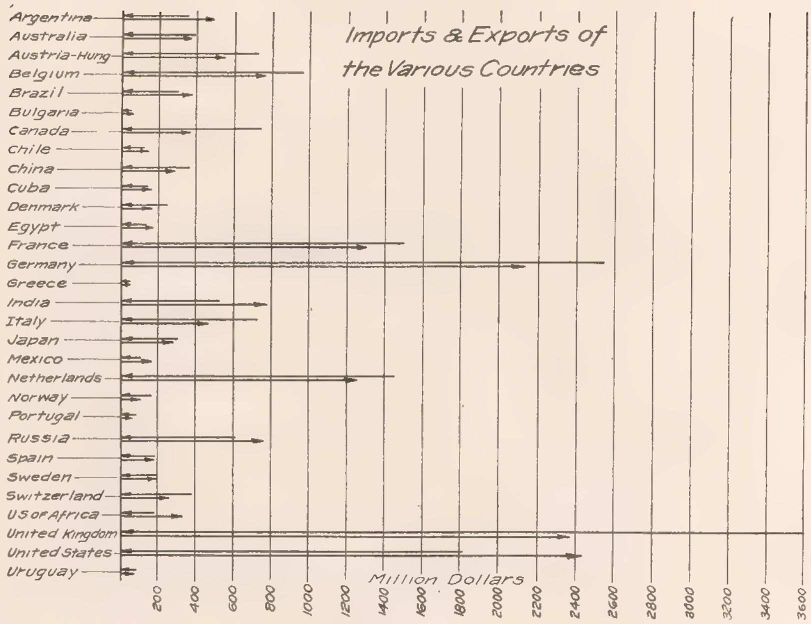
Imports & Exports of the Various Countries
Argentina
Australia
Austria-Hung
Belgium
Brazil
Bulgaria
Canada
Chile
China
Cuba
Denmark
Egypt
France
Germany
Greece
India
Italy
Japan
Mexico
Netherlands
Norway
Portugal
Russia
Spain
Sweden
Switzerland
U S of Africa
United Kingdom
United States
Uruguay
Million Dollars
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600

Fig. 5.

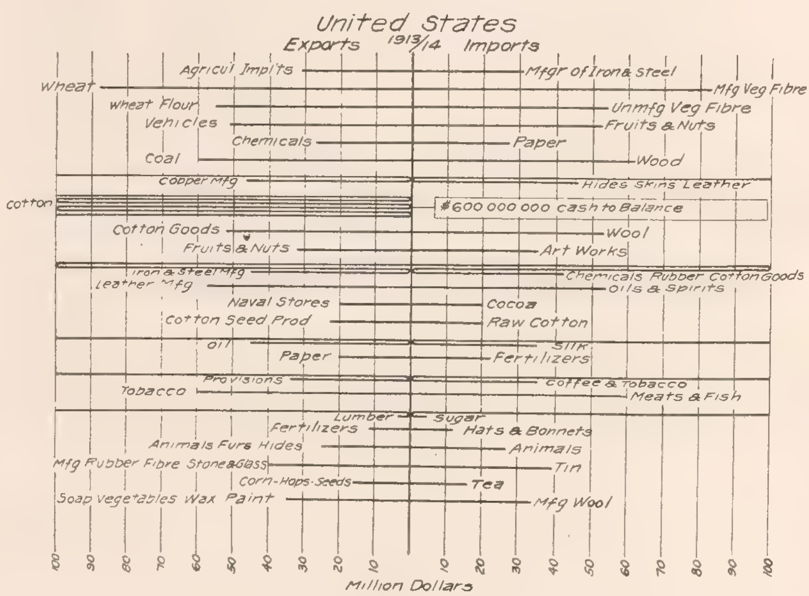
United States
Exports 1913/14 Imports
Agricul Impl'ts
Mfgr of Iron & Steel
Wheat
Mfg Veg Fibre
Wheat Flour
Unmfg Veg Fibre
Vehicles
Fruits & Nuts
Chemicals
Paper
Coal
Wood
Copper Mfg
Hides Skins Leather
Cotton
$600 000 000 cash to Balance
Cotton Goods
Wool
Fruits & Nuts
Art Works
Iron & Steel Mfg
Chemicals Rubber Cotton Goods
Leather Mfg
Oils & Spirits
Naval Stores
Cocoa
Cotton Seed Prod
Raw Cotton
Oil
Silk
Paper
Fertilizers
Provisions
Coffee & Tobacco
Tobacco
Meats & Fish
Lumber
Sugar
Fertilizers
Hats & Bonnets
Animals Furs Hides
Animals
Mfg Rubber Fibre Stone & Glass
Tin
Corn-Hops-Seeds
Tea
Soap Vegetables Wax Paint
Mfg Wool
100 90 80 70 60 50 40 30 20 10 10 20 30 40 50 60 70 80 90 100
Million Dollars

Fig. 6.

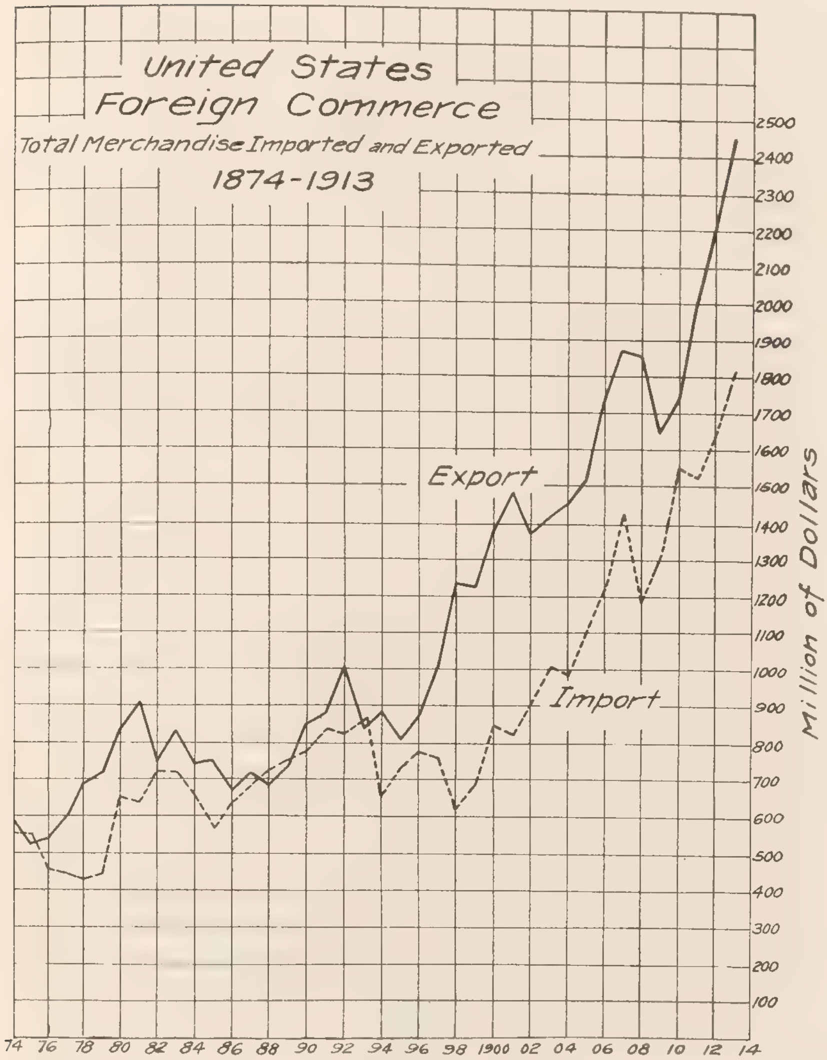
United States
Foreign Commerce
Total Merchandise Imported and Exported
1874-1913
Export
Import
Million of Dollars
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
74
76
78
80
82
84
86
88
90
92
94
96
98
1900
02
04
06
08
10
12
14

Fig. 7.

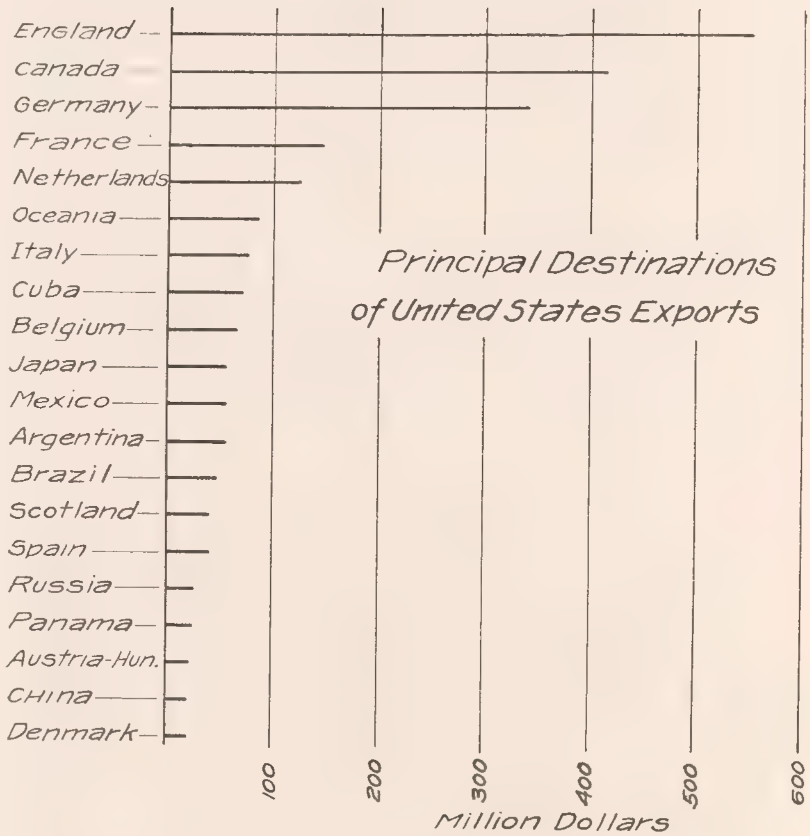
England
Canada
Germany
France
Netherlands
Oceania
Italy
Cuba
Belgium
Japan
Mexico
Argentina
Brazil
Scotland
Spain
Russia
Panama
Austria-Hun.
China
Denmark
Principal Destinations of United States Exports
100
200
300
400
500
600
Million Dollars

Fig. 8.

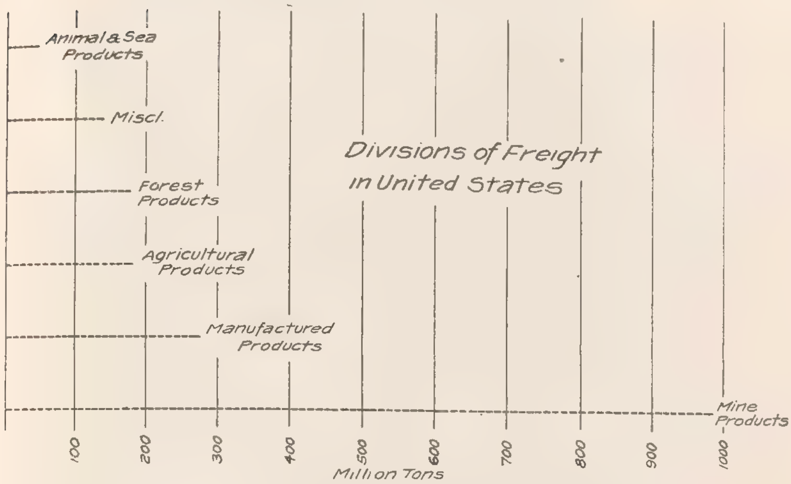
Animal & Sea Products
Miscl.
Forest Products
Agricultural Products
Manufactured Products
Mine Products
Divisions of Freight in United States
100
200
300
400
500
600
700
800
900
1000
Million Tons

Fig. 9.

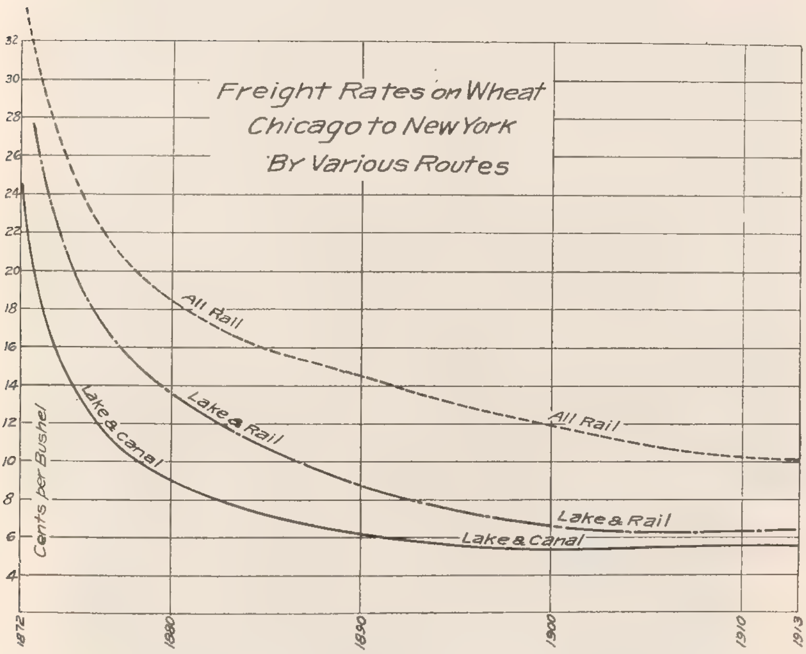
Freight Rates on Wheat Chicago to New York By Various Routes
All Rail
Lake & Rail
Lake & Canal
Cents per Bushel
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
1872
1880
1890
1900
1910
1913

Fig. 10.

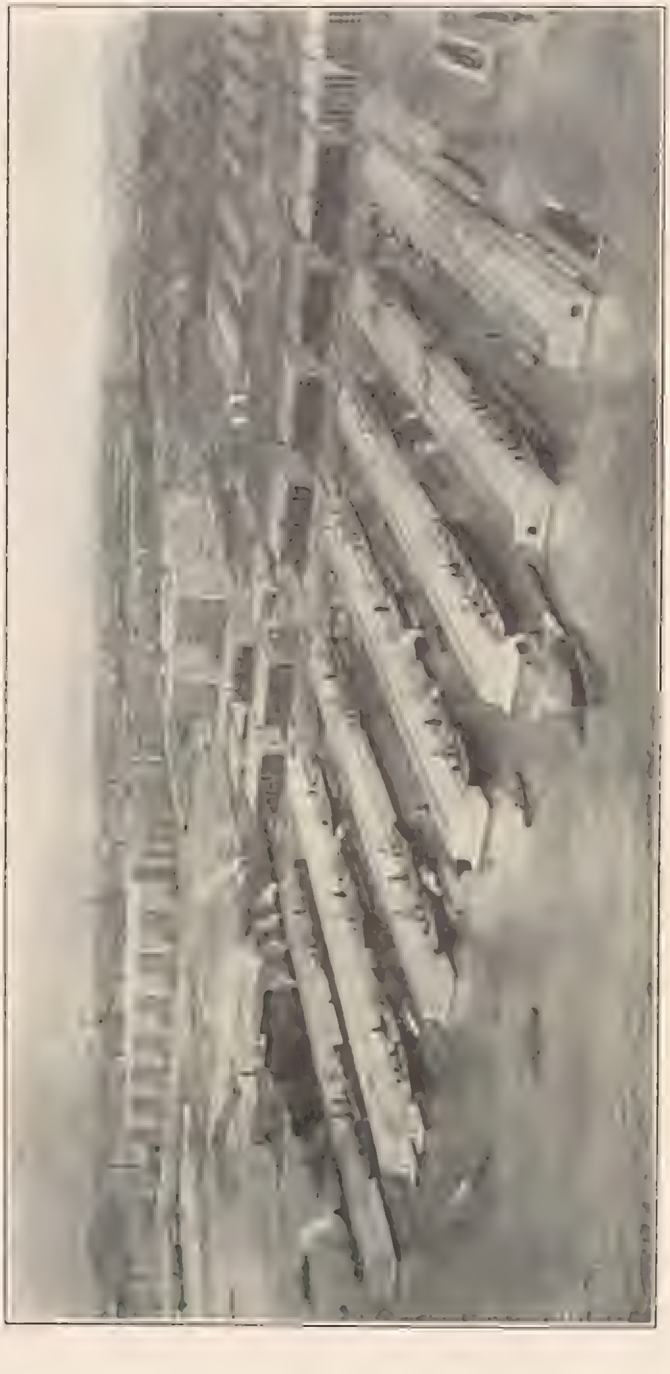

Fig. 11. Birds-Eye View of the Bush Terminal Co.'s Plant, Brooklyn, N. Y.

Fig. 12. Eight 4-Ton Cargo Derricks Each Equipped with Two 115-H.P. and One 25-H.P., 3-Phase, 25-Cycle, 220-Volt Motors. Balboa Docks, Panama.

Fig. 13. Discharging Coffee by Portable Conveyor at New Orleans. Slip to Wharf Shed is 100 Feet.

Fig. 14. Lumber Handling Crane.

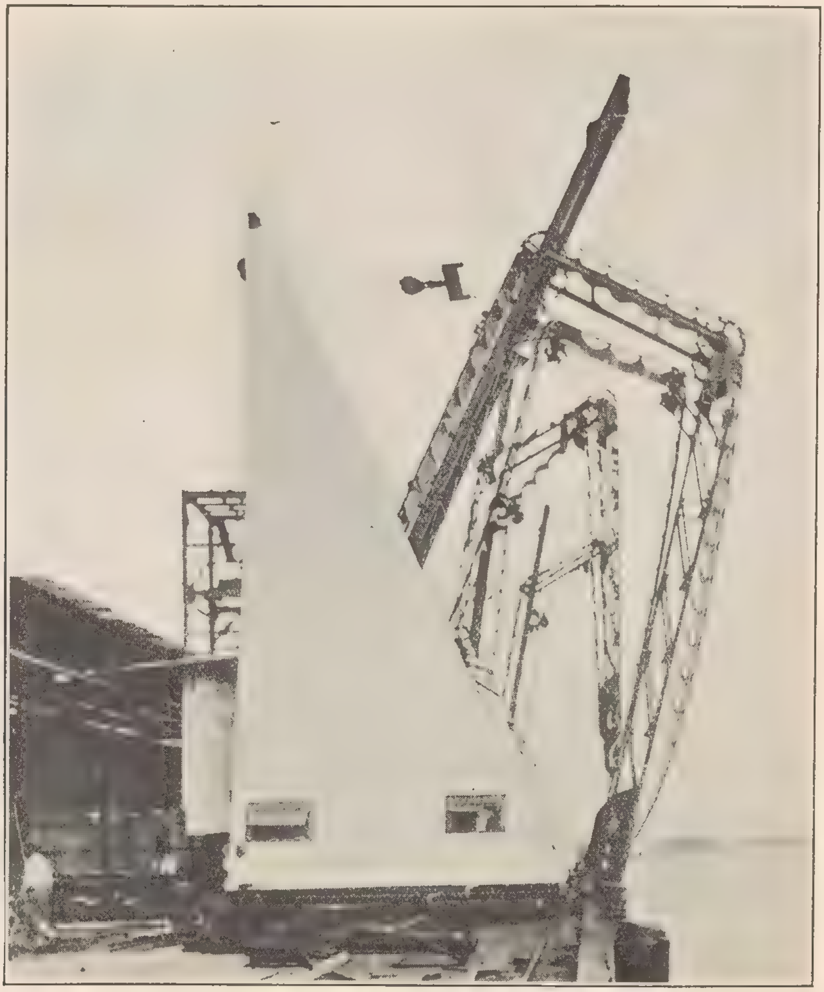

Fig. 15. Banana Unloaders at New Orleans Wharf.

Fig. 16. Ore Unloading Bridges.

Fig. 17. Storing Freight on Board Steamer from Electric Freight Truck.

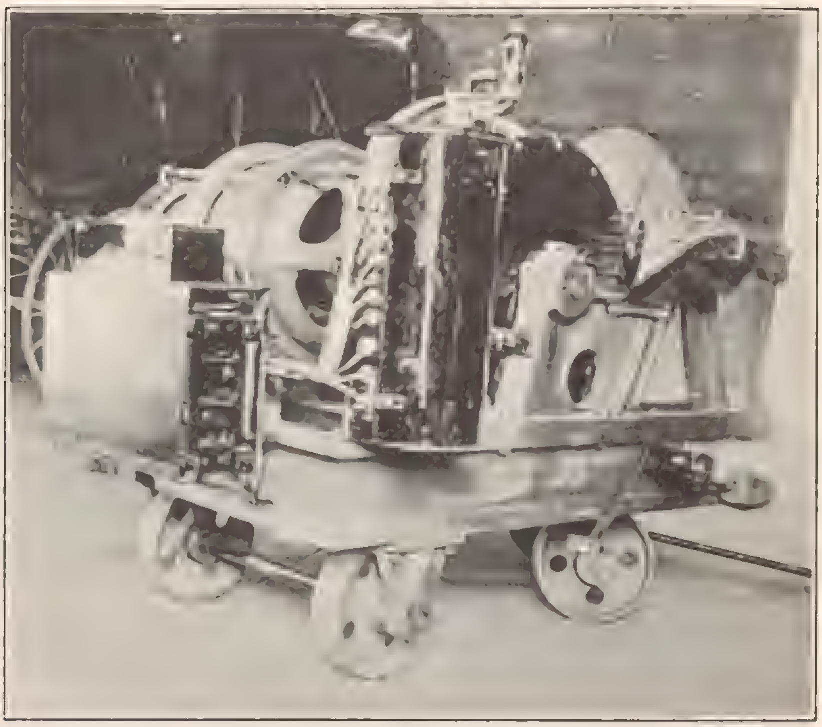

Fig. 18. Portable Dock Winch.

Fig. 19. Typical Pier Scene, Bush Terminal.

Paper No. 220

THE MODERN TREND IN AMERICAN MARINE TERMINALS.

By

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The last few decades have seen practically every great industry stimulated and intensified by the wholesale adoption of modern organization and modern mechanism.

No better example of this tendency can be found than in the improvements in the transportation of commodities between communities, by land and sea. Freight movements, in the broad sense, are carried out with marvelous dispatch, low cost and commendable safety, all making for an efficiency that does not leave much margin for improvement. Only very lately has this time and money saving movement invaded the terminals which, heretofore, have seemed immune to the infection of modern tendencies.

At the terminals, the meeting places of our galleys and caravans, things have stayed much the same. So true is this that could Pizarro return, he would find little to astonish him in these centers of turmoil and hurly-burly.

Progress is making itself manifest along well defined lines, and a few years will see improvements as revolutionary and far reaching in this work as have already materialized in all related lines.

In order to present a logical and thorough treatise on the most desirable lines of terminal progress and the ways and means for attaining a comparative degree of efficiency in the complex service rendered, it is necessary to resort to a subdivision of the matter, with systematic treatment of each phase.

The most salient lines along which improvements are noted and desired are:

Safety
Dispatch
Economy
Service

SAFETY.

Under the head of "safety" is placed the safeguarding of floating and rolling property at the terminals, the protection of employees, and fire prevention.

At large progressive seaports, particularly at those whose facilities are in part or wholly publicly owned, many of the following provisions for the safety of rolling and floating property are to be found, and are becoming considered in a greater degree. The deepening, widening and straightening of approach channels, with improved buoying and lighting by Federal authorities, are doing much to make safe and easy the arrival and departure of shipping. Compulsory piloting, while deemed a hardship by some navigators, tends toward reducing losses by collision or grounding, especially in ports where tidal and current conditions are severe and changeable. The gradual increase in the size and power of harbor tugs and the wonderful skill of tugmen are factors agreeable to all who go down to the sea in ships.

Dry docks and marine railways in sufficient numbers and of ample size inspire the confidence of foreign ship-owning companies and allow of periodical cleaning, even if no repairs are needed. While dry docks of enormous size are under construction and planned, there are many ships touching at our ports that could not possibly be docked on our coasts.

In ports, such as New York, where there is much car float traffic, recent improvements in floats and float bridges are notable additions to harbor and property safety features. The newer, all-steel, water-tight compartment floats, carrying twenty and more cars, are practically non-sinkable, and much more care and judgment are being used in the design and equipment of float bridges, thereby minimizing the damage to and loss of freight cars in this peculiar branch of traffic.

In terminal yards, the extensive and successful introduction of electric yard locomotives is largely accounted for by the reduction in damage to property by their use, where the entire work is largely starting, stopping and short shifting—requiring a maximum of control in order to avoid rough work. Clever and extensive yard-signal and switch-interlocking devices all lend their aid to the conservation of property.

Taking up the precautions necessary for the protection of employees, we come to a condition that has been neglected as far as terminals are concerned, though well advanced in almost every other industry. Such an advance is very desirable in this work, as great numbers of men are here employed in the most strenuous labor, under high pressure night and day, amid rapidly moving and swinging loads and under changing conditions, so that accidents of every kind are very frequent. The ambulance is as familiar a sight along the "beach" as the lunch wagon, largely because even the most obvious precautions are entirely neglected. If one should look for the one thing that best proves the backwardness of terminal development, it could be found in the circumstance under which men do their work.

Under ordinary accidents may be enumerated: Falling into hold; being hit by falling freight from sling or pile; being struck by broken gear, such as wire ropes, hooks, staging, etc.; injuries to feet and ankles, by hand and power trucks; torn hands, by bands and wire on packages and by box and bale hooks. Other accidents are all too frequent, such as falling into harbor; being suffocated by fumigating operations; being overcome by fumes, dust or poisonous exhalation from cargoes; scalding, from broken valves or steam pipes to winches; injuries due to shifting or banging cars without warning, etc. Stages are erected, to meet temporary conditions, on which men work, handling material under conditions that would not be tolerated in any other line of work.

Good drinking water is frequently not available or is not located nearby. Sanitary precautions and conveniences are absent or are of a low order. Poor food, improperly prepared, is served along the front from carts, under no supervision or inspection. The laborers frequent water-front saloons of the lowest order—unclean, unventilated and mismanaged.

Absence from work, due to accident or sickness, is hardly noticed, as most of the employees are "casual laborers" or shenangoes.

Therefore, it is clear that there is great necessity for improvement in the conditions surrounding the nearly a million terminal employees, and at least the ordinary, obvious precautions should be adopted to reduce the great economic losses now prevailing due to sickness and accident.

The matter of fire prevention is rapidly forging ahead, as is proven by the general introduction of large and efficient steam and steam-electric fire tugs in all ports of importance. Warehouses, piers and sheds are being piped for sprinkler systems, and the water-front skyline is becoming punctuated by elevated tanks for fire service duty.

Yard locomotives are being fitted with fire fighting apparatus, and being on the spot, often prevent serious fires among freight cars, inflammable freight and terminal properties. Smoking is universally prohibited in piers, and only recently have automobiles and power trucks been allowed access to these places. Electricity has largely superseded the open gas jet as a lighting medium, thereby adding another step in the right direction.

DISPATCH.

In the matter of "dispatch" we have probably the most important, and most sought after, phase of terminal activity. A reputation for dispatch is the most valuable asset that any port, terminal pier, or stevedore can have. Dispatch insures continuous and remunerative business. Dispatch is the antidote for congestion.

In the design of cargo ships, many improvements are manifest, looking to speedier discharging and receiving. The new cargo boats have large steam winches in greater numbers than formerly prevailed, and well they may, for the standby charge on a moderate-sized ship runs from $300 to $500 per day, and money cannot be better invested than in facilities tending to shorten the stay in port. Modern coastwise ships are provided with more and larger side ports. It is a new and good practice to provide an elevated position for the cargo winches, leav-

ing a clear deck for deck loads and placing the winch man in a more commanding position. Hatch covers have come in for their share of attention, and the old standard strongback construction, with hand boards, is giving way to hinged steel trapdoors of clever design that are quickly handled by the cargo winches and provide a certain closure when at sea.

The holds of the newer ships are free, or nearly so, from the stanchions that so profusely stud the working spaces of the older ships. The former tendency to specialize ships for certain cargoes has not been found expedient, as commerce does not usually provide similar cargoes both ways, consequently the normal cargo carrier is almost a universal ship. Donkey boilers are now of more liberal capacity, as in the older ships much delay is caused by lack of steam for all the winches without firing up the main boilers.

The greatest advance toward dispatch is attained in terminals by the use of mechanical devices for handling freight in and out of ships, to and from storage piles and warehouses, and into and out of cars. Many of the larger and more progressive ports are investigating and testing various electrical machines, and there is, at present, quite a commendable quantity of such machinery in the package freight work; but the surface has hardly been disturbed as yet, either in the design of such devices or in their general adoption. A brief review of progress, to date, along these lines is too important to be omitted.

Winches: Electric winches, single, double, and with one or two motors are in quite general use to supplant or supplement the ships' cargo winches. Head frames are provided on pier buildings to accommodate one whip, while the other is trained through the block or the ship's boom. Such apparatus provides greater speed, with greater safety, than is the case with steam, due to the uniform speeds, ample power braking and quickness of control that electricity provides. The most recent innovation in this country in this line is the use of a double portable master-controller carried by the winch operator, which gives him perfect control of both drums from any convenient position on the ship or elsewhere. The advantage of always having the draft in sight adds greatly to the dispatch, and this end can be attained in no other way.

Conveyors: Sectionalized portable conveyors of ingenious design and great utility are rapidly becoming common on the piers, where they are used to discharge from the decks of ships, lighters or barges to the pier or storage pile, without rehandling. A single whip, or two working in multiple from the same hatch, supply the conveyor, which makes the horizontal transfer at great speed. A remarkable feature of this type of machine is its reservoir capacity, or fly-wheel effect, by virtue of the receiving area provided through its constantly presenting new empty surfaces to the loading device. Power consumption is very low, and the machines are not expensive to install nor limited in their application.

Cranes: While much relied upon abroad, cranes are but little used along our coasts in the package cargo handling. Some of the most notable are: The banana conveyor cranes at New Orleans (ten in number), each with a capacity of forty-two bunches per minute; the battery of cargo cranes at Balboa, Panama Canal; and the variety of types seen about New York Harbor, which, however, are largely used for lighters and barges.

General: So much depends upon the proper storage of cargo in ships that much improvement in dispatch in that direction cannot be looked for with package freight.

One of the most striking advances in dispatch is found in the use of portable electric cranes for loading and unloading gondola and flat cars.

Another system which speeds up internal movements of freight is the trailer and tractor plan, whereby simple platform four-wheel trucks are towed in groups by an electric tractor, which carries no load itself. Trailers are provided far in excess of the number towed at one time, so that the tractor never waits for loading or unloading but picks up the trailers that are ready each time.

The pressure of factory production is as nothing compared with the pressure that traffic puts on the terminals. Each day's burden must be disposed of to make place for tomorrow's load. Like a man in a leaky boat, who must keep bailing or be swamped, the terminals are ever faced by the grave emergency of congestion, where dispatch is no more, and the trouble

spreads to unbelievable distances along the arteries of commerce. The ample provision of varied and well-adapted machinery is the simplest method of attaining dispatch and retaining it, and it is the line along which most terminal progress is being made at the present time.

ECONOMY.

This is usually of secondary importance to dispatch, but measured in money, it is, of all considerations, the phase of terminal work most promising of improvement. The cost of handling freight through terminals is enormous as compared with the cost of hauling the same freight from place to place. The reason for this high cost is the universal use of manual labor, which has been retained largely because it is plentiful in the coast cities. The farmer has not adopted his wonderful machinery, to the almost entire exclusion of manual labor, from any love for machinery, but from dire necessity. His load factor is low, for his machinery is of special nature for seasonal work, a couple of weeks per year being an average condition. With the terminals, the load factor could be nearly 100%, but not being forced into its use by the absence of good labor, the terminals have been satisfied to work along the old lines. The use of machinery well adapted for the work has in many cases cut the labor costs to one fourth the figure that formerly prevailed.

In a long, comprehensive series of tests of freight handling devices, made by the writer for the Board of Commissioners of the Port of New Orleans, a great quantity of data was accumulated, covering many movements of freight by various methods. Readings were taken repeatedly on every variety of manual work with which comparison could be readily made, when readings were taken on machine methods. By this means, parallel cases are compared, which would be difficult to do otherwise.

From these carefully recorded instances, it is found that (after charging the machine methods with all overhead, maintenance and power), costs vary from slightly more than, to as low as one fifth of, the manual labor cost, according to how well the machinery is adapted for the work. It is certain that no one machine or device can cover any great variety of the work

involved, and it is but fair to say that the most varied industry in the world requires a variety of machinery to do its work with economy.

Some of the very useful types of machines for reducing terminal costs are:

Industrial Trucks: These little machines are readily operated by longshoremen, and when the surrounding conditions are right, they cut the costs of moving freight to a marked extent. They work to best advantage on packages that can be readily handled by one or two men, because each piece has to be lifted on or off by hand, or by some other means. The distances must be rather great to make a good showing over hand trucks, and the approaches to loading and unloading points must be good.

Car Pullers: These machines may be vertical or horizontal; the vertical type can be set into a wharf, so that the drum only is visible. These pullers are very handy in minor car movements that would not warrant the calling of a switch engine. While the savings effected by these devices are indirect, they are nevertheless important. By moving cars from twenty to fifty feet, the cost of unloading or loading them can sometimes be cut in two; whereas, without this convenience, hand bars would have to be resorted to or the work done in an inconvenient manner.

Portable Cranes: The type using a storage battery for its source of power has a wide range of utility, with its most marked economies in the loading and unloading of gondola and flat cars. The machine, being a combined crane and electric truck, makes one handling of iron pipes, structural steel, timbers, logs, etc., between car and storage pile and gives the added advantage of economical tiering. Its greatest usefulness lies in short lifts of heavy weights, with moderate distance transfers. Another type is actuated by means of a motor having a cable leading to a receptacle or service station forming a part of the power distribution system. This machine is not self-propelling and is used principally to give unrigged barges, floats or lighters a rapid and economical cargo-handling equipment equal to or better than that of ships. These devices make the best showing on quantities of freight in units up to 2000-

pounds weight and requiring a considerable vertical movement. They discharge onto industrial trucks, trailers or hand trucks, or receive from them when loading boats.

There are many auxiliary devices that work for economy, among which may be mentioned:

Automatic Weighing Machines: These are provided as indicating and recording, and when the platform is set flush with the floor, loads are weighed without perceptible halt.

Good Lighting System: This is of so much importance that it may well come under "safety" and "dispatch" as well as "economy". With plenty of light, well and evenly distributed, errors in routing are avoided; greater speed can be attained; there is less liability of accident; and the necessary labor is worked to better advantage than would be the case in a poorly lighted space. Medium units well distributed are better than large units far apart, particularly when high storage piles cast black shadows for long distances. Petty pilfering is discouraged and smoking intruders are more easily kept away. When it is considered that forty 250-watt lamps can be lighted at a cost equal to the wages of one watchman, the economy of a well lighted terminal becomes apparent.

Adequate Power Distribution: When service stations are installed at frequent intervals along the piers, bulkheads, about warehouses, etc., motor-operated mechanical devices have a free range and can be put at work where the work has to be done. A lack of places where motor cables can be connected will often lead to the use of manual labor, while the machinery lies idle. About 200 ft. of cable is the maximum amount that can be used without excessive line drop, unless very heavy cables are used; hence, to give the desired range, stations should not be more than 300 ft. apart, and a much closer spacing is desirable.

Battery Charging Devices: Where industrial trucks, battery cranes or commercial trucks are used, a clean, light, roomy place, where batteries can be cared for and charged, is essential. There is no type of apparatus so responsive to close attention as the storage battery, or so inefficient and expensive, if not properly cared for. An elaborate system of records, involving the attendant in much clerical work, is not desirable,

and only absolutely essential data should be recorded. Where a terminal system covers a large area, small charging stations should be placed at accessible points to save long, wasteful runs to and from the central point, except when necessary for overhauling, testing, etc.

Tools: Under this head come all the accessories for the machines and operations, and a good supply of adequate tools will earn more dividends than can be imagined. Rope slings, chains, grab hooks, rail tongs, log tongs, skids, rollers, wire ropes, pinch bars, etc., are worth their weight in gold, and any attempted economy in supplying such things is certain to be overwhelmed by losses due to a lack of them.

SERVICE.

The service rendered by the terminal is manifold, not the least of which is its reservoir effect in smoothing out the friction and jolts due to various carriers working on an intermittent and non-synchronous basis.

In mechanics, wherever power is applied intermittently and a constant effect is desired, or where both power applied and power transmitted are intermittent or varying, a fly-wheel is interposed for the purpose of reserving the surplus power, returning same to the system whenever the demand exceeds the supply. The fly-wheel storage capacity tides the system over its deficient moments.

More appropriate, perhaps, to the line of thought to follow is the case of the elevated box provided by the excavating contractor into which the clam shell dumps its load regularly without regard to the vehicles employed for drawing away the spoil.

Here is a case where a simple box perfectly coordinates the digging apparatus and the vehicles, for one does not have to wait for the other; and each department works to its full capacity.

The why, where and when of reservoirs in freight handling systems may well be given much study by those who manage such operations and by those who are ambitious to improve the methods of carrying out such work.

First, let us make an inspection of the existing reservoirs

in the much broken and embroiled stream of freight traffic—these quiet pools that so frequently intervene in a manner distasteful to the efficiency expert and the designer of rapid transfer apparatus.

Beginning then with the broader reaches of the traffic, we find the great warehouse systems of the coast cities and of cities bordering on great productive areas. These are designed to smooth out the peaks and valleys of supply and demand, involving the welfare of the entire civilized world. They stand between the variables of production and demand, housing their wealth against the lean days and making possible the enjoyment of the fruits of the earth at all times and in all places.

The movements of the products of forests, field, mine and factory are affected by the seasons, by business conditions and by extraordinary events, as well as by the vagaries of land and sea transportation. The warehouses are, therefore, constantly filling or discharging, completely or in part, to break the abruptness of commercial changes, and are, therefore, valuable fixtures in the broad equipment of the traffic world.

The actual physical work required in the constant filling and emptying of these immense cellular reservoirs, the apparatus needed and used, as well as the proper coordination of the various systems of transferring, elevating and storing, present an abundant field for study, and one in which the reward is certain and remunerative.

In a few instances, very good results have been attained in the matter of service to warehouses; and in one case, there is a great system of warehouses under construction for which the manner and means of all freight movements involved have been carefully laid out in advance and the entire design bent to make every movement simple, inexpensive and rapid. It is expected that this work, when completed, will prove, beyond shadow of doubt, that warehouses should be designed around the transportation facilities, rather than to install the latter by a series of compromises after the warehouses are built.

Another prominent example of an unavoidable reservoir in freight traffic is the class made up of the pier shed of the seaport and the railroad freight house. These come closer to

the main current, and are exceedingly numerous and vary greatly in size and manner of performing their duties. Primarily, they smooth out the misses that occur between two or more intermittent carriers, standing as they do at the point where the freight is shifted from one form of carrier to another. They are, essentially, fly-wheels, receiving impulses and delivering impulses, remodeled, as required, for the moment.

Freight almost never, however desirable, passes directly from dray to car, from car to ship, from ship to car, or car to dray; always, there is at least the freight house or wharf interposed. To ignore or to eliminate this essential element in plans is to insure defeat. Admitting the necessity of these pools, it is best to work them into the scheme to advantage and amplify their usefulness.

A continuous contact of years with terminals has so far failed to show an instance of package freight, other than perishable fruit, passing directly from ship to car, or vice versa. There is the fact that freight cars bring small loads, intermittently, from many points, while the hold of a great ship requires an enormous amount of freight, practically all at once, to satisfy its appetite. The pier shed becomes an accumulator, as a more economic principle than holding the ship for the leisurely arrival of its outward cargo.

Another consideration, of a purely business nature, adds to the certainty and perpetuity of the intermediate storage, and that is the matter of checking, weighing, inspecting, sampling, re-coopering, etc. To the engineer, it would seem as though much of this mauling and man-handling of freight could be avoided or done once for all by some mutual agreement. This phase of freight handling could well form a chapter by itself, for the disturbance recurs at every turn and twist of the traffic and must greatly affect the overall cost of transportation, as it surely does the dispatch.

Having brought attention to the principal reservoirs now existing, and the why of their being, we will turn to the desirability of introducing still more pools, fly-wheels, or reservoirs, as they may be called, where freight is actually being moved. This may seem a long way from the usual mode of attacking freight handling problems; but practice with many

old and modern methods and devices has proven, again and again, that whenever two systems or devices are working in series and one or both are of a pulsating or intermittent nature, a reservoir is in order at the junction, to permit the full and steady operation of the whole system.

To illustrate: A coffee ship is discharging, by means of two whips in series, onto small four-wheeled hand trucks. Enough hand trucks and crews are provided to haul away the output of the whips, but due to the human equation, the trucks become grouped, so that at times they wait in line for their loads, only later to leave the ship unserved, and the whips and the workers on deck and in the hold must wait for the return of the head of the line. A sloping stage, of two or three truck loads capacity, eliminated this trouble and boosted the output to the limit of the whips. In this connection, it may be mentioned that a portable conveyor offers a still better solution; first, because it affords a continuous instead of an intermittent service; and second because it is inherently a reservoir by virtue of its surface velocity being greater than the feeding capacity of the whips, thus constantly presenting a clean surface alongside the hatch.

In a case where a portable conveyor was used to bring cement from a barge up a levee bank to discharge onto industrial trucks for a rather long haul to various piles, a similar scheme was adopted, as it was found necessary to either frequently stop the conveyor or litter the floor with cement, which interfered with the electric trucks. A smooth inclined stage of one and one-half truck-loads capacity furnished the needed fly-wheel, or reservoir, effect, so that space was always available for discharging the conveyor, and every truck found sufficient accumulation for quick loading.

Another kind of conveying apparatus, namely, the tractor and trailers, has in itself considerable capacity, by virtue of using three times as many trailers as are towed at one time by the tractor.

An elaborate and expensive special freight-handling machine is brought to mind in this connection, the failure of which was largely brought about by the lack of any latitude at the discharge end. Mathematical precision was required of the

operator at that end, hour after hour, and the eternal human equation, not being timed by cams to function at precise instants over long periods of time, nearly wrecked the machine, repeatedly damaged the merchandise, and made the work at that end very unpopular. Neither was there any optional capacity provided at the feeding end, and, as a consequence, the theoretical and guaranteed capacity was quite impossible of attainment.

CONCLUSION.

This brief review of the awakening of the terminals is, of necessity, but a skeleton outline of the lines along which the new progress is being made.

Safety to floating and rolling stock is practically guaranteed by the modern appliances and facilities now common. Loss and damage to materials in transit have been materially reduced of late by the introduction of continuous mechanical handling processes, and could be much further reduced if shippers would use proper care and forethought in packing goods. Safety to life and limb is still, as ever, a matter of chance. A strong effort should be long continued, to the end that safety devices, rules and supervision may prevail in the terminals to the extent that they do in other industries.

Dispatch has been wonderfully improved, largely by placing the congestion periods farther and farther apart. How prolific this feature is may be judged from the fact that our freight cars only average 24 miles per day, and an increase of one mile in the daily average would be equal to adding 100,000 cars to the active list.

Ships are no longer used as storehouses to any extent, as it is realized that dividends are earned at sea.

Economy is being attained largely by the introduction of machine methods, which tend also to reduce the possibilities of a complete tie-up from labor trouble.

Service rendered to shipper, carrier and consignee is being bettered in many ways, though largely through business relations, rather than through mechanical or engineering efforts.

Progress throughout all terminal relations must take place gradually, because commerce is of a willful nature and its

appurtenances have not been chosen and held onto through these many years without good reason. To attempt to regulate its comings and goings, its upstandings and downsittings, to accommodate the Utopian ideas of the remote designer is futile and harmful to the general spread of mechanics in freight handling.

For a generation, probably, the general scheme of commercial and traffic inter-relations will change but little, and it is certain that much can be done to reduce costs and better dispatch by the use of machinery—if the present methods are carefully studied and the apparent handicaps are circumvented and made to aid the work in hand.

Paper No. 221

AMERICAN GRAVING DOCK PRACTICE.

By

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During the decade which has elapsed since the last International Congress of Engineering was held in America, the most striking development in the construction of dry docks consists in the increased dimensions made necessary by the marvelous growth in size of ships. Ten years ago (see Fig. 1), the "Carmania" with a length of 678 feet, width 72 feet, and normal draft of 23 feet, represented the economic limit of commercial ships, while the 20,000-ton dreadnaught existed only on blue prints. Today the "Vaterland", 950 feet long, 100 feet in breadth, with normal load draught of 37 feet, is regarded merely as the forerunner of yet greater vessels, and the 40,000-ton battleship is no longer the dream of a visionary.

The provision of adequate means for cleaning and repairing the underwater bodies of these enormous floating structures presents problems of ever increasing difficulty to the maritime engineer whose business it is to contend with them. He must design for the ultimate investment returns if the project be a commercial enterprise, or, if a naval dock, for the peculiar demands of the service contemplated. He must design for safe, convenient, rapid and economical operation; he must select a site that satisfies all the desired conditions of approach; and he must devise methods of construction which will involve a minimum of risk and give the greatest assurance of satisfactory completion. Since no two locations are alike in every respect, it follows that the construction of each dry dock involves new problems. It is the object of this paper to review very briefly the manner in which these problems have been met and solved

in the principal American structures built since 1904, and to deduce therefrom a summary of American practice regarding the most important features of design.

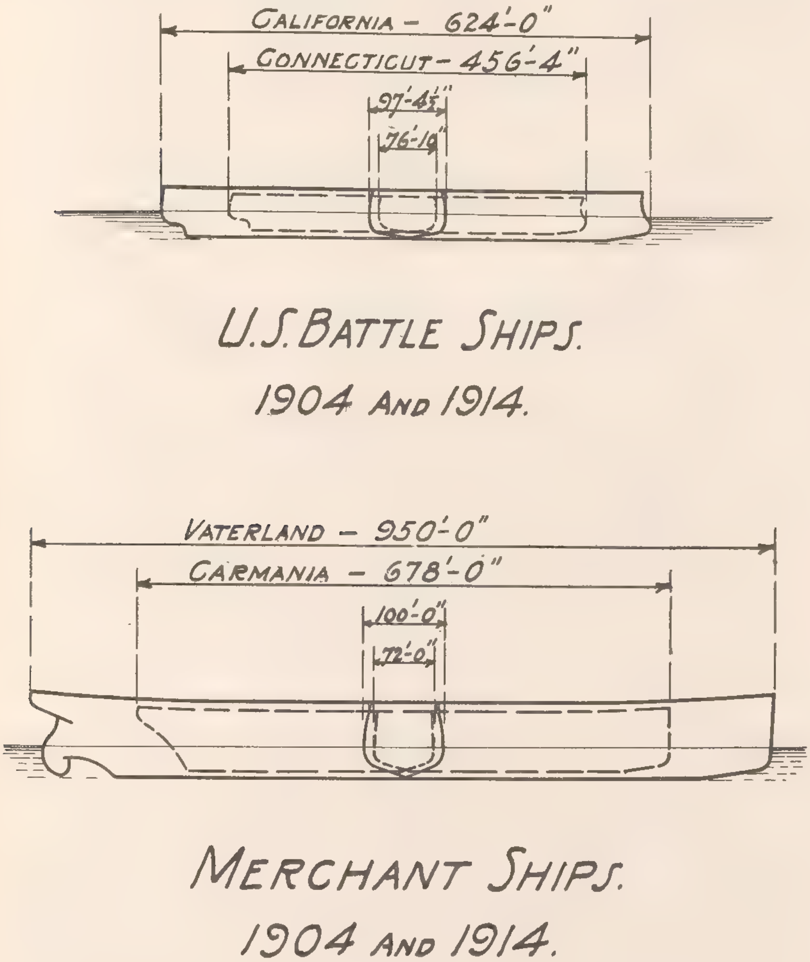


Fig. 1.

EXAMPLES OF DOCKS CONSTRUCTED OR PROJECTED DURING THE PERIOD 1904-1914.

Table 1 gives dimensions and other available data of the larger American dry docks constructed or projected during the last decade. The list of docks includes, for the sake of

comparison, a number of notable foreign docks, and typical cross-sections of the more important structures are shown in Figures 2 to 14. Only a few of those possessing peculiar points of interest, either by reason of size, design, or method of construction, will be described in greater detail.

Dry Dock No. 2, Boston:

Begun, 1899; completed, 1905; cost, $1,100,000. Subsoil, blue clay and gravel, the floor resting on blue clay, not water-bearing. The dock was designed for full hydrostatic uplift. No piles used. Mass concrete 1:2:5, aggregate either broken stone or gravel. Granite lined. Constructed in open excava-

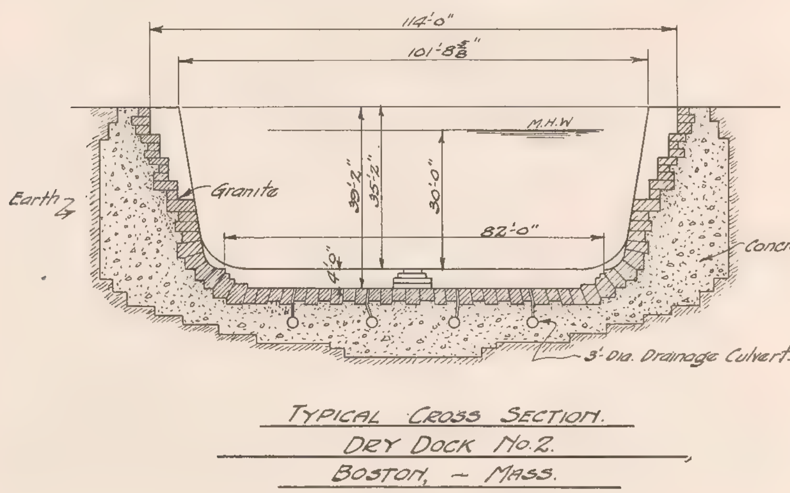


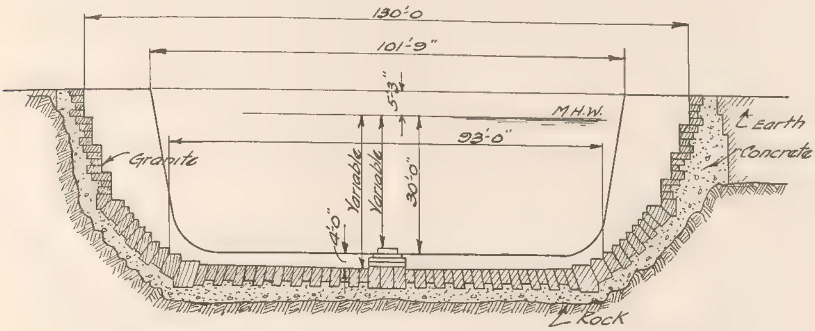
Fig. 2.

tion protected from the sea by a semi-circular cofferdam consisting of double sheet-pile bulkheads, clay filled. No difficulties were encountered. Cost per foot of dock $1490. Main pumps, two 48-inch centrifugal, horizontal shaft, direct connected to constant speed A.C. motors. Time of pumping from M.H.W., 2 hours. Time filling: 1 hour, 45 minutes. Gravity type dock. Section shown in Fig. 2.

Dry Dock No. 2, Portsmouth, N. H.:

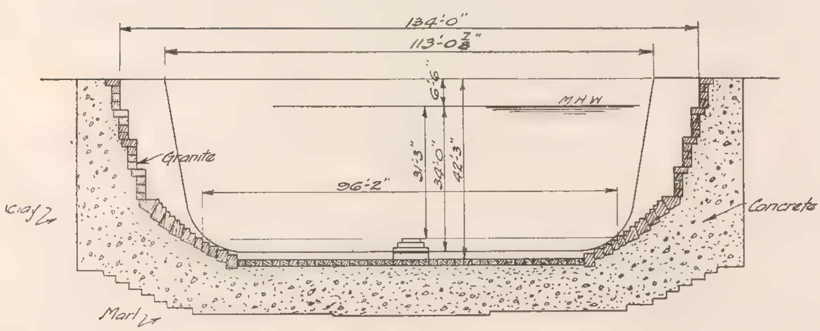
Begun, 1899; completed, 1905; cost, $1,122,800. Subsoil, trap rock with seams and fissures. Floor not keyed to rock and no floor bleeder pipes as designed. Holes drilled in

through paving in 1909; developed flow of water under 8-ft. head which disappeared entirely after a few minutes. Mass concrete of side walls, 1:3:5; floor 1:2:4. Granite lined. Constructed in open excavation behind sea face cofferdam. No



TYPICAL CROSS SECTION.
DRY DOCK - No. 2.-
PORTSMOUTH, - N.H.

Fig. 3.



TYPICAL CROSS SECTION
DRY DOCK - No. 1.-
CHARLESTON, - S.C.

Fig. 4.

difficulties encountered. Some seepage through joints in lining. Cost per linear foot of dock, \$1520. Main pumps, three 45-inch double suction, horizontal shaft, centrifugal, direct connected to variable speed D.C. motors. Speed control by armature resistance. Pumps operate well at constant speed. Time of

pumping from M.H.W., 2 hours. Time of filling: 2 hours, 20 minutes. Veneer type. Section shown in Fig. 3.

Dry Dock No. 1, Charleston:

Begun, 1902; completed, 1908; cost, $1,250,000. Subsoil, river mud, blue clay and marl. No piles; dock rests directly on marl bed. Designed for full hydrostatic uplift. No test holes have been drilled in floor to develop actual conditions but from the impervious nature of bottom it is possible that the dock is subjected to no appreciable upward loading. Concrete, 1:3:6. Dock constructed in open excavation behind cofferdam. No difficulties encountered. Cost of dock per lineal foot, $1990. Main pumps, four 36-inch centrifugal, single suc-

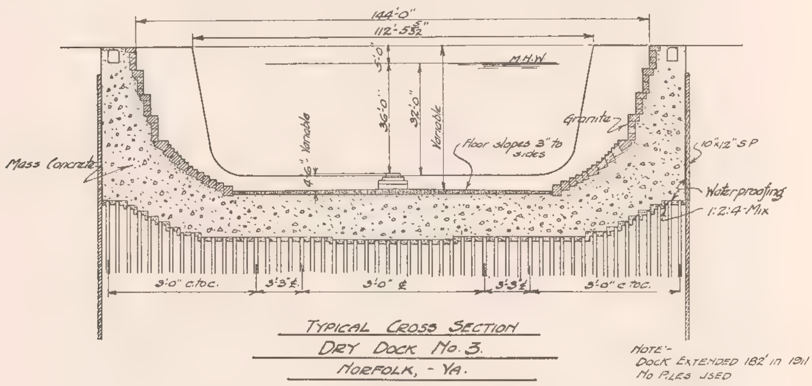


Fig. 5.

tion, vertical shaft, direct connected to constant speed A.C. motors. Time of pumping from M.H.W., 1 hour, 46 minutes. Time of filling: 1 hour, 45 minutes. Gravity type. Section shown in Fig. 4.

Dry Dock No. 3, Norfolk:

Begun, 1903; completed, 1908. Extension begun, 1910; completed, 1911. Original cost, $1,200,000; total cost as extended, $1,729,000. Subsoil, river mud, blue clay and marl. Original dock founded on piles, extension, directly on marl. Designed for full hydrostatic pressure. Holes, drilled in floor in 1914, indicate only about 20% of the pressure due to static head and this decreased to zero after bleeder was allowed to flow freely for a few minutes. Concrete 1:2½:5. Lined with

granite; walls and floor backed and soled by 12 inches of 1:2:4 mixture. The original dock was constructed in open excavation behind cofferdam. 12x12 timber sheetpiling driven at backs of walls. Extension constructed without sheet-piling. No difficulties were encountered. Original cost per lineal foot \$2180. Cost per lineal foot as it exists today, \$2390. Main pumps, two 54-inch centrifugal, double suction, horizontal shaft, direct connected to variable-speed A.C. motors, 25% speed reduction. Time of pumping from M.H.W., 1 hour, 50 minutes. Time filling: 1 hour, 45 minutes. Gravity type. Section shown in Fig. 5.

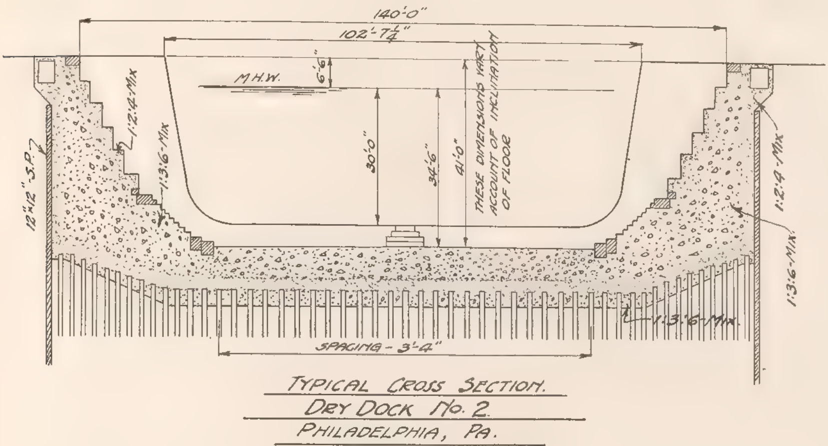


Fig. 6.

Dry Dock No. 2, Philadelphia:

Begun, 1899; completed, 1908; cost, \$1,472,000. Subsoil, sand and gravel. Founded on piles. Designed for full hydrostatic uplift, which condition probably exists. Concrete 1:2½:5, with 1:2:4 backing for side walls. Granite lining. Constructed in open excavation behind cofferdam and inside enclosing sheet-pile bulkhead. No difficulties encountered. Cost per lineal foot, \$1980. Main pumps, three 45-inch horizontal shaft, centrifugal, direct connected to variable speed D.C. motors. Speed varied by armature resistance. Time of pumping from M.H.W., 1 hour, 30 minutes to 15 inches above floor, 3 hours, 45 minutes, total. Time filling: 1 hour, 28 minutes. Gravity type. Section shown in Fig. 6.

Dry Dock No. 2, Mare Island:

Begun, 1899; completed, 1910; cost, $1,680,000. Subsoil conditions, hard yellow clay overlying soft rock which disintegrates under exposure to air and water. Floor not in water-bearing strata. Dock founded on piles averaging 34 feet long on 2 to 4-feet centers. Dock designed for full hydrostatic uplift and pull on pile heads allowed for. Mass concrete, 1:3:6. Granite lining. First attempted to construct in open excavation but upon failure of original contractors their successors adopted the so-called crib method. The site was first excavated by suction dredge and piles driven and cut off under water. A floating crib was constructed of longitudinal and

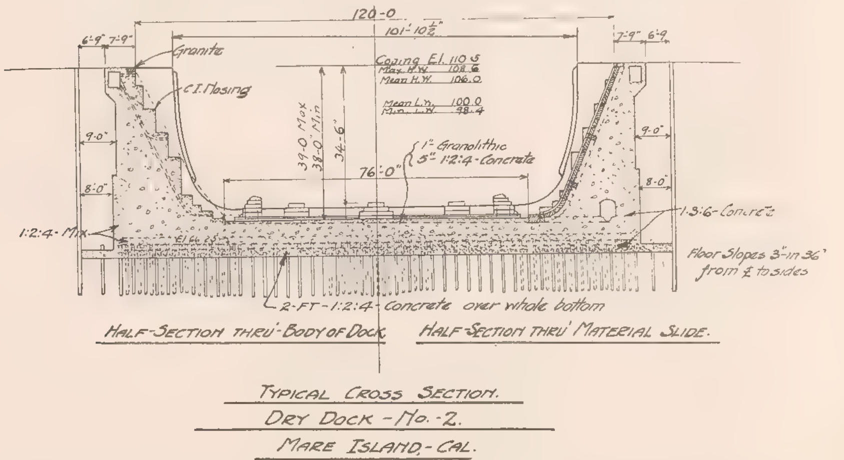


Fig. 7.

cross struts, the side strips of which were designed to act as wales for alignment of sheet-pile bulkhead. The outer wales were held in position by round pile dolphins. The cribbing was sunk in place as successive tiers were built, and sheet-piling was driven from the top. Sheet-piling was located far enough outside the dock section to avoid interference with the placing of concrete. No difficulties were encountered after this method was adopted. Cost of dock per lineal foot, $2270. Main pumps, two 54-inch double suction, horizontal shaft, centrifugal, direct connected to constant speed A.C. motors. Time of pumping from M.H.W., 1 hour, 35 minutes. Time filling, 40 minutes. Gravity type. Section shown in Fig. 7.

Dry Dock No. 4, New York:

Begun, 1905; completed, 1912; cost, $2,855,000. Subsoil conditions, clays and fine sands overlying glacial drift. Designed for full hydrostatic uplift. Foundations, concrete filled pneumatic caissons, designed both for bearing and anchorage. Outside line of caissons continuous, forming water cut off. The principle of design is a reinforced concrete floor slab at once held down and supported by the outer continuous caissons and three intermediate rows of caissons 7 feet square in section, spaced 20 feet longitudinally. The large cost of the dock is due to the failure of several contractors prior to final award to

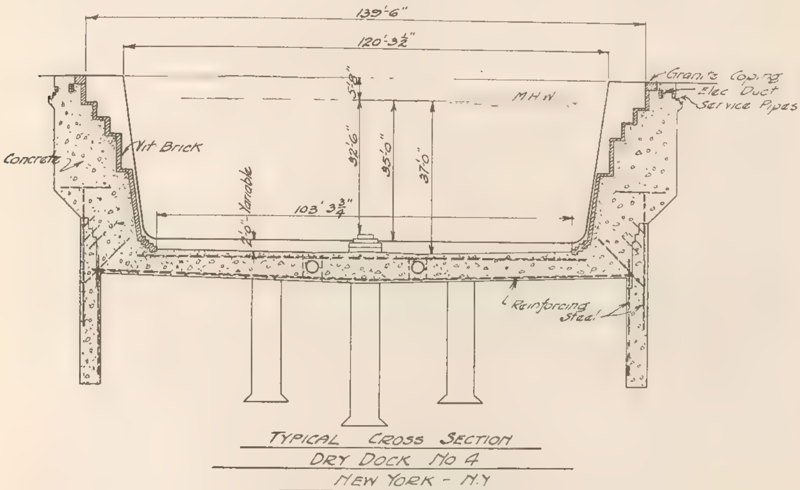


Fig. 8.

the concern which carried the work to completion. Cost per lineal foot, $4100. Main pumps, three 48-inch vertical shaft centrifugal, directly connected to constant speed A.C. motors. Time of pumping from M.H.W., 1 hour, 20 minutes. Time filling, 48 minutes. Reinforced dock. Section shown in Fig. 8.

Dry Dock No. 2, Puget Sound:

Begun, 1908; completed, 1913; cost, $2,097,000. Subsoil, cemented sand and gravel "hard pan" with springs. No piles. Designed for full hydrostatic uplift. Observations since construction demonstrate existence of full design loading. Mass concrete, 1:10 (1:3-1/3:6-2/3 gravel). Walls, granite lined,

floor, cement finished. Dock constructed in open excavation behind sea cofferdam. No difficulties encountered and no delays. Bottom springs easily controlled by "sumps" and 12-inch terra cotta pipe. Cost of dock per lineal foot $2530. Main pumps, four 48-inch, single suction, vertical shaft, centrifugal, direct connected to constant speed A.C. motors. Time of pumping from M.H.W., to top of keel blocks, 81 minutes; from top of keel blocks to floor of dock (one pump), 40 minutes. Gravity type. Section shown in Fig. 9.

Dry Dock No. 1, Pearl Harbor:

Contract first awarded in 1909. After two failures due to lack of appreciation of foundation conditions, and after the

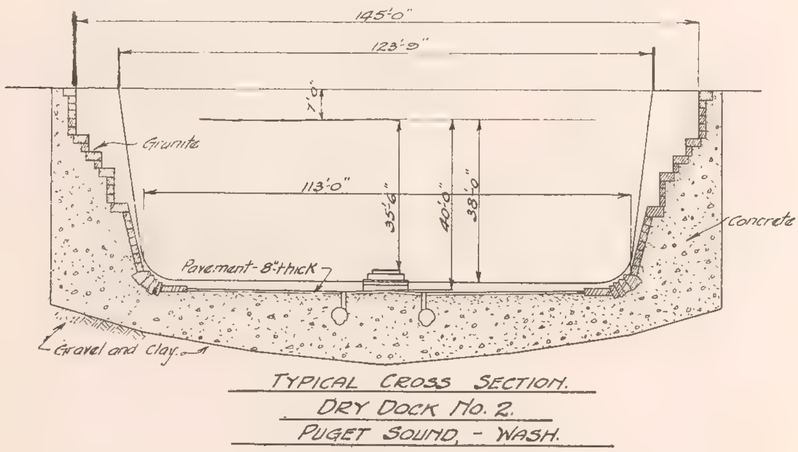
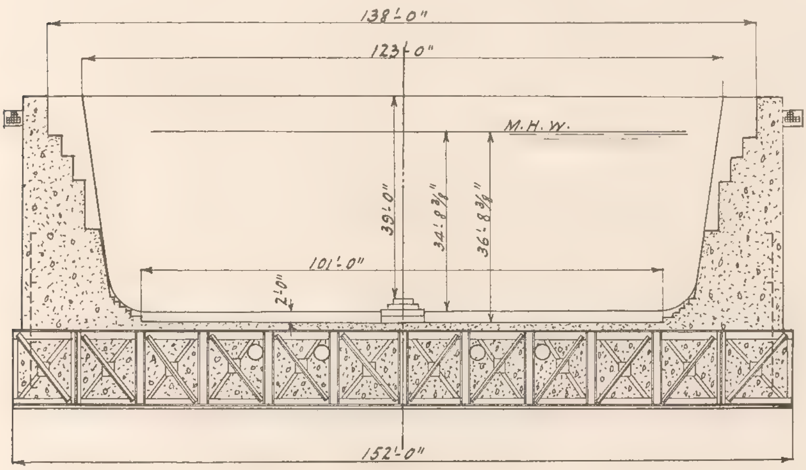


Fig. 9.

delays attending settlement of the questions growing out of the failures—questions affecting both the structural and financial features of the project—work on a modified design involving entirely new methods of construction has only recently been resumed. The sub-surface conditions at the site are approximately as follows: 8 to 13 feet of indurated lava mud of a hardness corresponding to firm shale; 45 to 60 feet of broken coral ranging in size from "finger" to "nigger" heads of considerable magnitude; and an underlying bed of brown lava mud of from 16 to 24 feet thickness. Below this bed are alternating layers of coral and lava mud of varying depths. The

continuity of the various layers can not be depended upon. The "brown lava mud" is practically impervious but the coral beds offer little if any obstacle to the free flow of water.

The method of construction originally contemplated consisted in dredging the dock prism and enclosing same in a sheet-pile cofferdam; driving foundation piles through water by means of followers to such depths as to insure penetration of impervious lava mud and a grip on the underlying water-bearing coral stratum; placing a bottom layer of tremie con-



TYPICAL CROSS SECTION
DRY DOCK No 1
PEARL HARBOR, T.H.

Fig. 10.

crete of sufficient thickness to engage the full holding down power of the piles and to secure a water seal; and, after unwatering, the completion of concrete work in the dry. This method was abandoned, after the various failures, on account of the impracticability of driving piles of sufficient penetration, and the inability to devise other means of holding down the bottom during the unwatering of the partially completed sections in the absence of the contemplated anchorage value of piles.

The present method of construction was devised by Civil Engineer H. R. Stanford, U. S. N., Chief of Bureau of Yards and Docks. It consists essentially in the partial construction of the dock floor sections of steel framing and concrete on the deck of a floating dock; the attachment thereto, while yet supported by the dock, of a steel floating ballast tank; the undocking of tank with attached floor section; the lowering of the section to its previously prepared foundation by admission of water to ballast tank; the completion of the dock section in the dry after unwatering certain of the tank chambers designed for the construction of side walls and unfinished parts of the floor—utilizing the weight of the water remaining in the tank to hold down the work until the entire mass of concrete is in place; and, finally the flooding of completed section, detachment and removal of tank, and repetition of procedure for the next section. It is estimated that the entire work can be completed without further difficulty within three years.

The steel framing of floor sections is designed to carry the stresses induced by the various operations involved in the method of construction and will, at the same time, provide amply for all tensile stresses to which the completed dock will be subjected. The side walls are also reinforced. Mass concrete is to be mixed in the proportions of 100 pounds of cement to 3/4 cubic foot of local coral sand, 1 1/2 cubic feet of lava rock screenings, and 4 cubic feet of broken lava rock aggregate. The pumping plant will consist of four 48-inch single suction, vertical shaft, centrifugal, direct connected to constant-speed A.C. motors. Reinforced type. Section shown in Fig. 10.

The cost of the completed dock will be $4,442,000, or approximately $4300 per lineal foot of overall length.

Dry Dock for the Port of Boston:

Not yet begun. The amount alloted for the structure, complete, with all equipment, $3,000,000. Rock foundation. Side walls, cement finish, with granite coping and altar treads. Proposed method of construction, open excavation behind cofferdam. No difficulties contemplated. Gravity type side walls, veneer type floor. Mass concrete, 1 barrel of cement, 10 cubic feet of sand, 15 cubic feet of broken stone or gravel. This dock was designed by Civil Engineer DeWitt C. Webb, U. S. N.,

under the general supervision of Mr. F. W. Hodgdon, Chief Engineer of the Directors of the Port of Boston. Section shown in Fig. 11.

Dry Dock at Balboa, Canal Zone:

Under construction. Estimated cost, not known. Foundation, rock. Side walls, gravity type, with steel reinforcement, floors, veneer. This dock will be described in detail in papers to be submitted to the International Engineering Congress by the designers, Civil Engineer H. H. Rousseau, U. S. N., Engineer of Terminals, Canal Zone, and Civil Engineer F. H. Cooke, U. S. N., Principal Assistant. Section shown in Fig. 12.

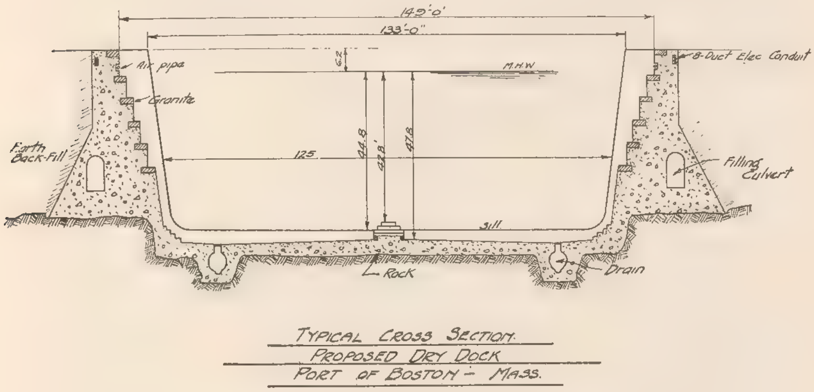


Fig. 11.

With the exception of the last two docks, all the foregoing structures were designed by the Bureau of Yards and Docks, and Corps of Civil Engineers of the Navy. The rather unique design of Dry Dock No. 4, Navy Yard, New York, was developed by Civil Engineer F. R. Harris, U. S. N.

A review of American dock practice would be incomplete without mention of the proposed docks for Quebec Harbor and the Port of San Francisco. The design for the former was prepared under the supervision of Mr. E. D. Lafleur, Chief Engineer, Department of Public Works, Ottawa, Canada, and for the latter by Mr. Hugo P. Frear, Chief Engineer, Union Iron Works Dry Dock Company, San Francisco, Calif. The characteristics of these docks are given in Table 1, and the cross-sections are illustrated in Figures 13 and 14.

The remainder of this article will be devoted to a discussion of the salient features of dry dock design as based upon a study of structures already built or projected, and upon an estimate of probable future requirements.

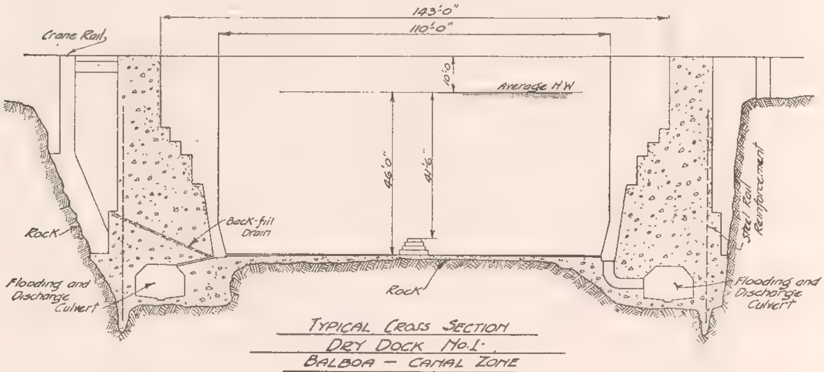


Fig. 12.

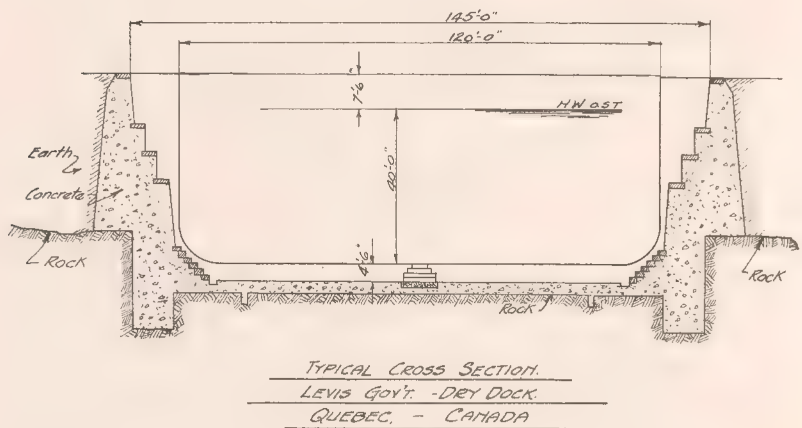


Fig. 13.

DRY DOCK DESIGN

Choice of Type:

With marine railways, patent slips, hydraulic lifts and similar devices eliminated from discussion by their capacity limitations, the choice of type for a docking appliance for battleships or large commercial ships is reduced to two: the graving dock and the floating dock. The limits of this paper prevent a discussion of the respective merits of the two types, even if the

existing literature on the subject were not so exhaustive as to render the task unnecessary, but it may be said that, for large ships, the choice is governed not so much by questions of cost, safety, convenience or economy of maintenance and operation, as by the characteristics of the harbor and the subsoil conditions at the site.

Generally speaking the harbors on the Atlantic coast of North America are shallower, and it is only by the outlay of great sums that they can be maintained at depths sufficient to accommodate modern deep draught vessels. In order to dock a vessel drawing 35 ft. in a steel floating dock, a basin 65 feet

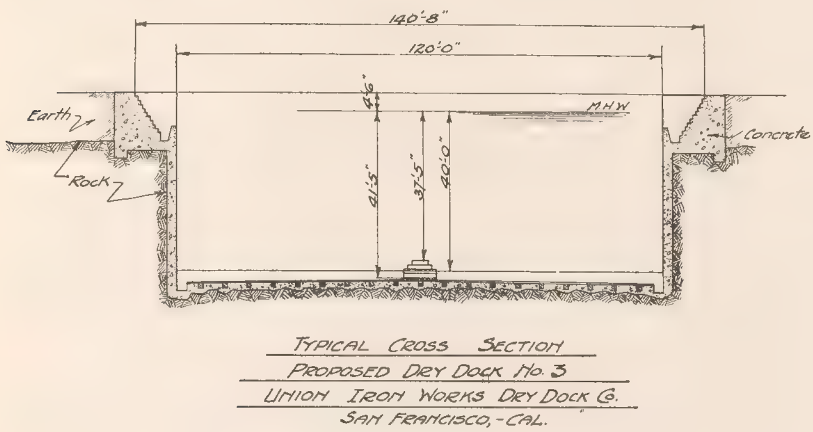


Fig. 14.

deep would be required. Such depths are not available in the harbors of Boston, New York, Philadelphia, Baltimore, Norfolk, or Charleston, and since all of these harbors are more or less subject to silting, the cost of maintaining an artificial docking basin would very probably prove a deciding factor in favor of the graving dock.

Subsoil conditions on the Atlantic coast vary. The New England coast ports offer, as a rule, rock foundations which eliminate serious construction difficulties and insure permanency. At New York, alluvial clays and fine water-bearing sands overlying an ancient glacial moraine, present difficulties in the construction of deep docks which materially increase

costs. This circumstance, together with the congested waterfront and the consequent high value of real estate, may render the adoption of a floating dock advisable for a New York commercial dock yard. At Philadelphia, Norfolk and Charleston, the subsoil is either coarse sand, heavy blue clays or marls, offering no difficulties to a pile founded structure constructed in open cofferdams. The maintenance of deep basins at any of these harbors would be so difficult and expensive that the graving dock seems to be clearly indicated. The harbors on the gulf and the Caribbean Sea are of the same general character as those of the South Atlantic States, except where the existence of coral adds to the expense of constructing graving docks by the difficulty of excluding water from the excavation which its presence usually involves.

The harbors on the Pacific Coast are characterized by ample depths for floating dock operation, and by subsoil conditions favorable to graving dock construction. The choice of type for Prince Rupert, Vancouver, Seattle, and San Francisco would probably be governed by special requirements and conditions, but assuming that either type would fill every demand of the dockmaster with equal satisfaction, the floating dock should find here a wide field of usefulness.

Choice of Site for Graving Dock:

A commercial dry dock should be located on water of such depth as will admit of the approach of the largest vessels contemplated at all stages of tide. There should be a clear, wide and deep channel from dock to home piers and to the open sea. The entrance to the dock should be protected from heavy seas and its axis should lie, as nearly as possible, parallel to the direction of the prevailing winds and should head with, rather than across or against, the current. In a tidal basin, where there is a reversal of current direction, the dock may be located for convenient entrance at high tide. It is essential that there be ample turning space in front of the entrance and, if practicable, a training pier should be provided for control in heading in.

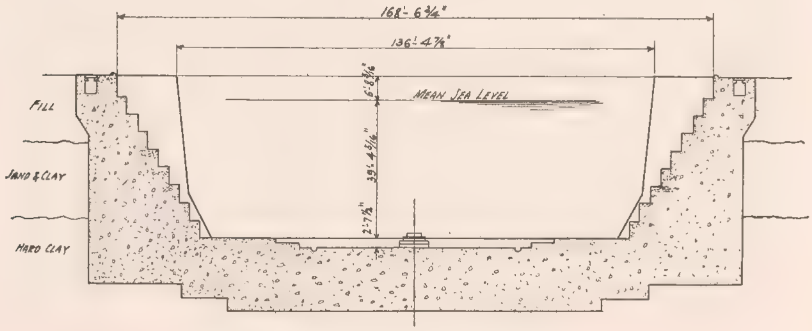
Except for purely military purposes, a graving dock should be located in proximity to labor and material markets and to shipping centers.

General Dimensions:

The dimensions of a graving dock must be determined by consideration of its contemplated use and the general nature of the project. For commercial use, the necessity of reducing fixed charges to the minimum will limit the size of the structure to that which will just accommodate the largest ships to be served. For years many engineers have held that the dimensions adopted for the locks of the Panama Canal should govern the size of graving docks for naval purposes, but recent developments of the European war and the growing popularity of the double dock, would indicate that the designers' judgment should not be so limited. The Canal locks are 1000 feet in clear length by 110 feet in width. With an intermediate sill a dock 1000 feet long would not accommodate two modern dreadnaughts and would just take the "Imperator" comfortably. It would seem that the comparatively slight increased cost necessary to obtain a dock capable of taking two 650-ft. battleships, is warranted by the resulting military advantage. This is particularly true when local conditions favor the construction of a double ended, or double entrance, dock. It is therefore believed that a naval graving dock should approach 1300 feet in clear length.

A dock with breadth sufficient to accommodate a ship of 110 feet beam would fulfill all normal requirements that can now be foreseen, but extraordinary circumstances may render a wider dock desirable. Professor Luigi Luiggi, one of the most eminent authorities on dry dock design, has expressed himself in favor of a width of 135 feet, and bases his opinion upon a recent experience when he was confronted with the problem of docking a crippled ship floated to the dock entrance by side pontoons. He advocates a dock capable of taking both ship and pontoons under such circumstances. In view of the present use of submarines and contact mines, like occurrences may not be an infrequent incident of naval warfare, and one such emergency in the useful life of the dock might well warrant the additional expense,—not so much because of the monetary value, but because of the need for the military unit endangered. The writer would therefore concur in Prof. Luiggi's recommendation for a dock with from 120 to 135 feet clear width on block level.

Such a dock should probably be reinforced for off center dockings so that in its normal operation the full capacity could be advantageously used by docking smaller ships in parallel. The amount of water to be pumped at each docking would be very appreciably increased, but the additional expense would be a minor consideration as compared with the military insurance resulting. It is worthy of note in passing that Prof. Luiggi has already put his ideas as to dock dimensions in practice in the case of the Naval dock at Taranto, which, when completed, will have a clear width five feet above the sill at entrance of 121 feet (see Fig. 15).



Typical Cross Section
Dry Dock
Taranto, Italy.

Fig. 15.

The draft over sill to be provided for commercial docks will, as in the case of length and breadth, be determined solely by the draft, in docking trim, of the largest vessel to be accommodated. In deciding on the draft for naval docks, however, it should be borne in mind that it is not always expedient to lighten vessels for docking and that the dock, in case of war, may be called upon to take a ship damaged by shot or torpedo and down by the head or stern. The modern naval collier of the "Orion" class will, when loaded draw over 33 feet, while the latest dreadnaughts draw 30 feet. It is conceivable that such ships could, from torpedo fire, have their forward compartments flooded so as to trim 40 or even 45 feet by the head

and still be able to make the dock under tow, if the channel from the sea permits. Under such circumstances the lack of dock capacity might be attended with almost fatal consequences. If, therefore, harbor conditions permit, the modern naval dock should have at least 40 feet over the sill at mean high tide level.

Number of Sills:

Two entrance sills are desirable in all large docks to facilitate repairs to groove and the cleaning of caisson seat. An intermediate sill would be a doubtful investment for a commercial dock since the occasions when a "long time" job could be placed in the inner chamber while the outer is occupied by transients, would not be of sufficient frequency to warrant the cost of the additional groove and caisson. A certain economy in pumping might be attained by using one chamber only when small ships are docked, but the saving would hardly pay interest on the increase in the fixed charges.

For a naval dock yard it is believed that long docks should have two intermediate sills. A dock 1300 feet in length, as recommended herein, should have a central sill and a sill at 400 feet from the head. Such a structure would provide two 650 feet docks, or one of 900 and one of 400 feet, and thus serve the purpose of two docks for dreadnaughts and one of capacity sufficient for the largest modern passenger ship.

Closure:

The type of closure universally used in American practice is the floating ship type caisson. It is economical, efficient, safe and simple in operation. It is also slow, requires, when not in use, berthing space valuable for other purposes, and sometimes gives trouble in harbors where the range of tide is great unless especially designed for low water dockings.

Gates with either vertical or horizontal axes are not adapted for use in silt bearing waters such as are found in the majority of Atlantic coast harbors. The older American dry docks, built for the wooden sailing ships of the forties, were equipped with gates, but these were later abandoned and caisson seats installed.

The rolling caisson has important advantages in time economy, independence of the state of the tide, and in the fact that

it requires no outside berthing recess. On the other hand it involves the construction of an expensive caisson chamber and runway, sometimes introducing complications in foundation conditions, and it is troublesome to clean and repair. Its expense is probably the strongest bar to its adoption.

Head:

It is essential that a dock shall furnish the maximum of docking capacity for the investment and for the land space occupied. Good designing will therefore provide for a vertical face head so that the docking length and over-all length will be as nearly equal as possible. In plan the semi-circular shape will give the greatest strength for the least cost. If a future increase in length is contemplated, the section at the head should be designed to withstand the maximum hydrostatic pressure with dock full, so as to permit the use of the dock after the extension has been excavated and during its construction. Temporary ends are not advisable even from the standpoint of economy.

Altars:

The arrangement of altars depends largely upon the practice of local dockmasters in the docking of ships. Unquestionably, the flat side slopes of the timber docks, so popular twenty years ago, offer important advantages in the way of light and ventilation. With the wider and deeper docks now demanded, these advantages are obtained only by heavy increase in first cost. The wide dock also entails an additional outlay in cranes of longer reach in order to plumb the center of ships accommodated. The general practice of the Bureau of Yards and Docks is to provide an altar at or about mean high water, and two, or possibly three, similar altars separated by intervals of from four to eight feet. These altars have a width of from two to three feet. The face of side walls from the lowest altar is usually battered 1 to 8, and the junction of side walls and floor is broken by a series of steps.

Lining:

The majority of American graving docks are lined with granite for protection from frost and wear. It is entirely possible to make concrete so impervious as to be practically as durable as stone but to do so requires a degree of skill and care

more often found in the laboratory than in the field, and for this reason it is believed to be poor business policy to dispense with a hard lining of some character for dock walls in locations subject to heavy frost action. Treads of altars and stairway surfaces should be paved. Dock No. 4, Navy Yard, New York, is lined with vitrified brick, and has passed through four winters without signs of deterioration. Experience with brick lined docks and locks abroad has been entirely satisfactory and its use will undoubtedly become more general in this country.

Floor Drains:

Quite a number of American docks depend for longitudinal drainage on a floor inclination from head to pump-well, or open side gutters, but the latest designs provide culverts embedded in the floor concrete. It has been found that great convenience results from the recent use of flexible connections between the ships' scuppers and the floor drainage culverts in Dry Dock No. 4 of the New York Navy Yard, and the importance of keeping ships' crews directly under the supervision of disciplinary authority at all times may very possibly result in the adoption of this plan for other docks and the retention of floor culverts on this account.

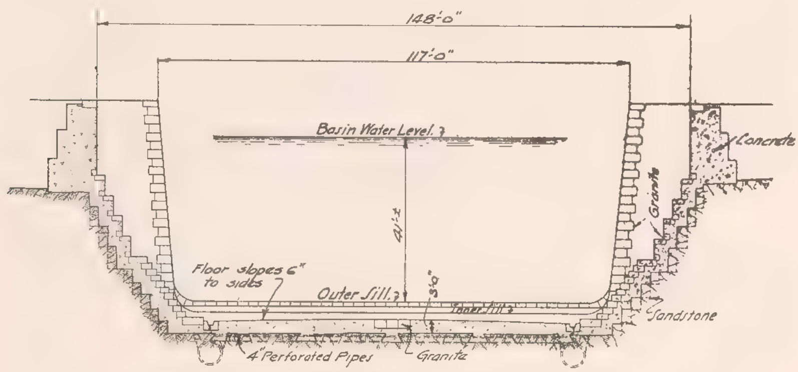
Floor:

The older American docks have floors paved with granite; more recent examples omit all floor lining or paving and rely upon the troweled concrete surface or a granatoid coating. Some foreign docks are cement paved with a belt of granite under the keel blocks. (See Fig. 16.) A better solution, from the viewpoint of the operator, is the wooden floor at such an elevation above the concrete surface as to permit free drainage. Such a floor would be dry and sanitary and comfortable for workmen, would permit of "dogging", and afford a pleasing appearance.

Blocks:

Keel blocks should be spaced 24 inches on centers for modern battleships. Blocks are usually clear white oak and are built up to a height of from four to four and a half feet above the floor. Docking block bearers are spaced 4 feet on centers and extend from keel blocks to side walls.

Taking the cross grain crushing strength of white oak at 400 lbs. per square inch (factor of safety of three for 3 per cent height deformation), the safe load for blocks of 3 square feet bearing surface is 86 tons, or 43 tons per linear foot of supported keel. With an arrangement of docking keels as shown for an assumed 30,000-ton battleship in Fig. 17, it will be seen that the usual block spacing of 24 inches is ample for that part of the ship resting directly on the blocks. A certain portion of the ship, however, overhangs the blocks both forward and aft and this brings a greater load on the end blocks. Assuming an elastic ship and rigid blocks and assuming further that the



TYPICAL CROSS SECTION
ROSYTH DRY DOCK.
ENGLAND.

Fig. 16.

weight of the overhanging portion is borne by a length of blocks equal to the length of overhang, as shown in Fig. 15, the necessity for additional supports under this load becomes apparent. In a number of the more recent docks the after blocking is being doubled.

In this connection attention should be invited to the danger of having supports too unyielding, in view of the impossibility of grounding uniformly. Should the ship take the blocks stern first, rigid blocks would be liable to result in serious strains.

Caisson Grooves:

No substitute has yet been found for granite as a facing for grooves. Needless to say the bearing surfaces should be abso-

lutely plane and true. The stone should be twelve cut and the greatest care should be exercised in the inspection of the blocks. Various materials have been used for gaskets for the contact faces of entrance caissons. Rubber is most widely used, but canvas, frayed hemp rope, and wood have given good service. Many foreign docks use greenheart and in at least one American dock soft white pine, at a cost of one-fourth the rubber gasket it replaced, has proved durable and has given a tight entrance.

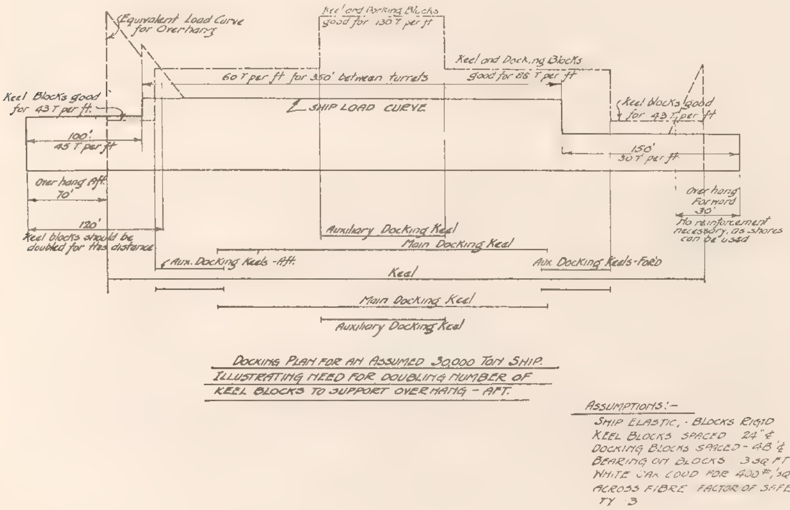


Fig. 17.

Flooding:

Older American docks were usually flooded through valves in the caisson. More recent examples, in addition to caisson valves, have flooding culverts through the side walls and yet later designs contemplate the use of the drainage culverts for flooding through openings in the floor, so distributed that disturbances from the inrush of water may be avoided. Probably the best example of flooding through the floor is furnished by the Gladstone dock of Liverpool harbor. (Fig. 18).

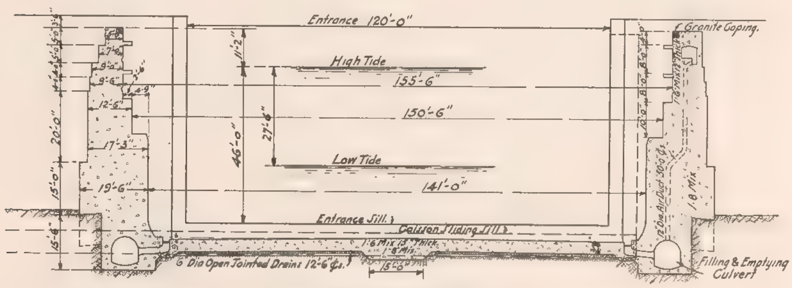
Dock Fittings:

Heavy cast iron bollards should be placed around the dock periphery at intervals of 50 feet. They should be at least 16 inches diameter and, on account of the high freeboard of the

modern battleship, should be provided with Norman bars, cast lips, or button heads. Steam, air or electric driven capstans should be provided at intervals of 150 feet and should be designed of capacity varying from 20 tons at 30 feet per minute to 6 tons at 100 feet per minute. They should be arranged for hand operation so as to be independent of the power source. The head line capstan should be so designed as to give a slower speed in addition.

Stairs:

There should be at least two stairs on each side of the body of the dock and a double stairway at the head. The English practice of supplementing the stairway by iron ladders does not appear to merit consideration on account of the danger attending their use.



TYPICAL CROSS SECTION
GLADSTONE DRY DOCK
LIVERPOOL

Fig. 18.

Dock Cranes:

The increased width of dry docks, to keep pace with the growth and size of ships, entails additional expense in dock cranes, on account of the increased reach necessary to plumb the center of ship on the blocks. In designing for increased reach, consideration should also be given to increased capacity, and it is a question if, instead of the 40- or 50-ton cranes now used, apparatus capable of handling the largest naval guns would not be warranted. A "hammer head" traveling crane or an overhead bridge traveler with height sufficient to clear fire control masts, and main purchase capacity of 120 tons, would add enormously to the efficiency of docks for naval purposes.

Pumping Plant:

Dry dock main pumping units are almost universally of the centrifugal type, driven by electricity, steam or Diesel engines. The pumps may be installed with shafts horizontal or vertical. Horizontal shafts if direct connected to the drives, necessitate an installation in a dry well which is expensive and sometimes hard to maintain. This arrangement also involves friction losses in the suction and discharge pipes and connections. Vertical pumps are better adapted to the conditions since they permit of an arrangement in which the pumps are located at the bottom of a wet well and the driving motors well above the water or even on the dock coping level, thus insuring a gravity flow to the pumps or, in other words, eliminating the suction lift.

The selection of the drive depends upon the local costs of the various kinds of power, cost of labor, number of dockings per year, available capital, annual costs of repairs and carrying charges. Exclusive of pumps and valves, which would have to be installed with any type of drive, the first cost of plants operated by electric motor, condensing engine, Diesel engine, or steam turbine, such as would be required for pumping a 1300-ft. dry dock, would be as follows:

Electric Motor	from	$ 60,000	to	$ 75,000
Condensing engine	from	275,000	to	290,000
Diesel engine	from	225,000	to	250,000
Steam turbine	from	240,000	to	260,000

The annual operating cost of each type would, of course, vary with the cost of power and other local conditions, but it may be stated roughly that, for the plant idle, the annual operating cost for the plants operated by condensing engine, Diesel engine, or turbine, would be approximately the same, and four times the annual cost of the plant operated by electric motors. The operating cost of the electric driven plant continues to be materially lower than either of the others considered up to 110 pumpings per year. Beyond this point it would seem that the Diesel engine installation is the most economic from the operators' point of view. The comparison would be very much more

in favor of electric motors in locations where the cost of current is less than 2c. per kw-hr.

Since it is rarely necessary to exceed 100 pumpings or 50 dockings a year, it would appear that the electric driven plant is most economical both as to first cost and operation, besides offering marked advantages in the way of elasticity and convenience. In locations where the cost of electric power is relatively high, or where such power is not available, engine driven equipments may be used to advantage. The adoption of these units, however, limits the arrangement to horizontal shaft pumps, unless gearing or belt drives are provided. Consequently the engines must be located at such heights above the dock floor as to be within the limits of practical suction lift, in most cases below tide level and therefore subjected to accidental submersion. For an annual number of dockings in excess of 50, the operating and carrying costs of engine driven equipments,—particularly Diesel engines—are materially less than of the electric type. The economic advantage is, however, offset to a certain extent by the time lost in starting on account of banked fires or lack of starting air charges,—a disadvantage which might assume a material importance in times of emergency.

Pumping units are designed to meet the special conditions of the particular dock. Pumps giving the highest over-all efficiency consistent with ruggedness and simplicity of operation are preferable to those of relatively high efficiency at certain stages, but requiring step bearing pressure pumps, pressure lubricating systems, oil pumps, oil tanks and like auxiliary apparatus. In American practice, pumps capable of maintaining a discharge velocity of 16 feet per second at zero head and 12 feet per second at maximum of 35 feet, have given satisfaction. For large docks a pumping plant designed to empty in less than 2½ hours would hardly be warranted.

There would seem to be no mechanical reason why the screw impeller lift could not be adapted to dry dock use. A rough illustration of such installation is shown in Fig. 19. Until more data are available for the preparation of a detailed design, this scheme can only be offered as a suggestion. It would result in a very considerable reduction in first cost of pump-well con-

struction and since driving motors could be used of commercial speeds, would involve a simpler and more economical machinery installation. If an over-all efficiency of 50 per cent could be obtained, the proposition would merit consideration in the design of new docks.

Structural Design:

No dock design should be undertaken until after a complete sub-surface exploration by means of borings. For the preliminary study it is only necessary to make borings at sufficient intervals for general control. Having determined the loca-

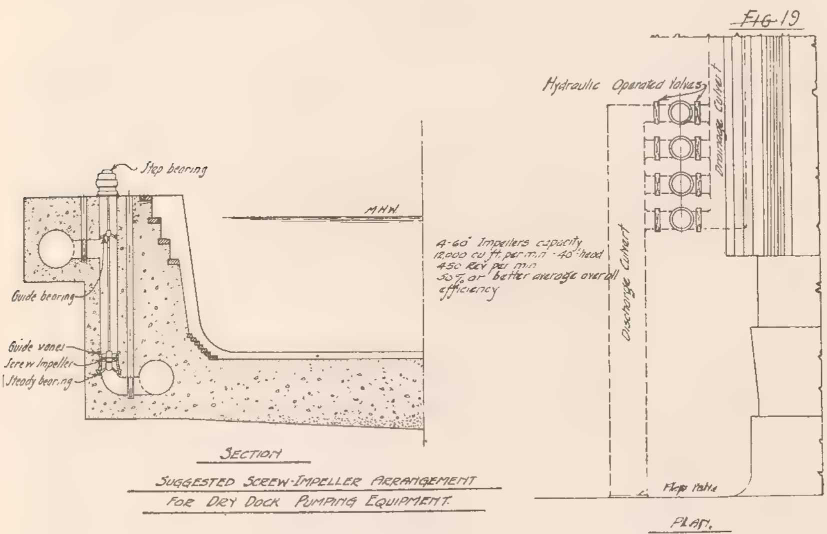


Fig. 19.

tion of the dock from this control, the dock area should be developed by borings on 25-ft. squares, unless the site is underlaid by a consistent stratum of good rock. In sands, marls, clays and soft strata the borings should be made with great care and should be carried down at least 150 feet, or even more if circumstances warrant. Samples of material should be taken from each class encountered and the evidence as to whether it is water-bearing or not should be noted. From these data, in conjunction with such surface indications as may be available, are obtained the design assumptions; weight dry and submerged, and angle of repose of the material to be retained by side walls;

bearing capacity of supporting beds; hydrostatic pressures to be anticipated; and unwatering difficulties.

If full hydrostatic uplift beneath the completed dock floor may be expected, the dock, as a whole, must either be of sufficient weight to balance the upward forces, or some means must be resorted to for pinning it down, either by keying to bed rock, utilizing the pull on pile heads or caissons, or by leaving open drain pipes in the bottom for relieving the water pressure.

For the purpose of this paper, docks are classed as "gravity", "reinforced", or "veneer". The gravity type dock is one which depends on the weight of masonry to balance upward pressures and which carries all stresses by its masonry alone. A reinforced type dock depends upon embedded steel for all tensile stresses and, to some extent at least, upon the holding power of piles or caissons for balancing uplift. A veneer type dock is one which consists essentially of a comparatively thin concrete lining on rock excavation.

Modern docks are usually constructed of concrete, either plain or reinforced. In a gravity or reinforced type of dry dock, the floor acts as a beam with end thrusts, and the stresses can be most conveniently analyzed by assuming a voussoir with imaginary joints. The forces acting upon such a voussoir are the lateral thrust of retained earth, lateral water pressure, upward water pressure, weight of masonry, and concentrated ship loads. If the earth is not capable of sustaining the loads imposed by the weight of masonry directly applied, the floor of the dock must be so designed as to distribute the load within the safe bearing values of the soil.

With an assumed cross-section and ascertained loads, stress diagrams are drawn for the investigation of stability, under the following assumed conditions:

(a) Dock empty, major limits weight of back-fill and flattest angle of repose.

(b) Dock empty, minor limits weight of back-fill and steepest angle of repose.

(c) Dock full, major limits weight of back-fill and flattest angle of repose.

(d) Dock full, minor limits weight of back-fill and steepest angle of repose.

TABLE I. CHARACTERISTICS OF THE PRINCIPAL GRAVING DOCKS CAPABLE OF ACCOMMODATING LARGE SHIPS.

Country.	Name of Dock.	Commercial or Naval	Length on Floor.	Width of Entrance.	Width on Floor.	Width of Coping.	Depth of Water on Sill.	Material of Construction.	Closure.	Altars.	Foundation.	Sub-surface Conditions.	Constructed.	Cost of Completed Dock.	Intermediate S[illegible]
United States	Boston No. 2.	Naval.	686' 0"	73' 0¾"	72' 0"	114' 0"	30' 0" M. H. W.	Concrete, granite lined.	Caisson, ship section.	4 on either side between vert. center of wall and coping.	Earth. (Blue clay)	Blue clay and gravel.	1905.	$1,100,000.00	
United States	Portsmouth No. 2.	Naval.	667' 6"	73' 0¾"	80' 0¾"	130' 0¾"	30' 2⅝" M. H. W.	Concrete and granite	Caisson, ship section.	4 on either side between vert. center of wall and coping.	Rock.	Rock.	1906.	$1 122,805 59	
United States	Norfolk No. 3.	Naval.	684' 6"	79' 1¼"	83' 0"	136' 0"	34' 0¾"	Concrete and granite.	Caisson, fin keel.	4 on either side between vert. center of wall and coping.	Piles and marl.		1910-11.	$1,728,965 93	
United States	Philadelphia No 2.	Naval.	680' 10½"	73' 6"	82' 10¾"	142' 2¾"	29' 10¾" M. H. W.	Concrete, granite lined entrance.	Caisson, ship section.	6 on either side Remaining distance steps.	Piles.		1908	$1,[illegible]	
United States	Charleston No 1.	Naval.	500' 6"	76' 6⅝"	80' 0"	134' 0"	34' 1⅛" M. H. W.	Concrete and granite.	Caisson, fin-keel.	4 on either side between vert. center of wall and coping.	Earth.		1908	$[illegible]	
United States	Mare Island No. 2	Naval.	681' 10⅝"	71' 6¼"	76' 0"	130' 0"	30' 3⅝"	Concrete, granite lined entrance.	Caisson, ship section.	4 on either side between vert. center of wall and coping.	Piles.		1910	$[illegible]	
United States	New York No. 4.	Naval.	649' 9"	103' 0¾"	103' 3¾"	139' 6"	35' 5½" M. H. W.	Concrete, brick and granite.	Caisson, hydrometer type.	4 on either side between vert. center of wall and coping	Caisson-concrete.		1912.	$2,854,54[illegible]	
United States	Puget Sound No. 2.	Naval.	756' 8"	98' 4⅝"	92' 0"	145' 0"	38' 0" M. H. W.	Concrete and granite	Caisson, hydrometer type.	4 on either side between vert. center of wall and coping.	Earth.	Cemented sand and gravel (Hard pan)	1908.	$2,096,827 1[illegible]	
United States	Pearl Harbor No. 1.	Naval.	755' 0"	98' 6"	101' 0"	138' 0"	34' 8⅝" M. H. W.	Concrete, granite entrance.	Caisson, hydrometer type.	4 on either side between vert. center of wall and coping.	Earth and lava.	Earth and lava.	1909.	$2 567,08[illegible]	
England (Liverpool)	Gladstone.	Commercial.	1020' 0"	120' 0"	141' 0"	155' 6"	46' 0" at High Tide.	Concrete	Caisson, sliding type, also ship	2 on either side between vert. center of wall and coping.	Bed rock.	Bed rock.	1910.	$15,000,000.00	Yes
United States	Boston	Commercial.	1162' 0"	120' 0"			44' 9⅝" M H W					Ledge, solid rock		$[illegible]	
Canada (Quebec)	Levis.	Commercial.	1120' 0"	120' 0"	100' 0"	144' 0"	44' 0" H. W.	Granite coping.	Outer caisson rolling. Inner caisson floating.	4 on either side between vert. center of wal. and c[illegible]	Solid rock	Rock.	1913		Yes: 500', [illegible]
[illegible]	3 mosy	Commercial.	1000' 0"	100' 0"			33' 4" H. W								
United States	San Francisco.	Commercial.	1096' 0"	120' 0"	120' 0"	140' 8"	42' 6" H. W.	Solid rock and concrete.			Solid rock.	Solid rock.		$2,000,000.00.	Yes; 434', 662
Malay Peninsula (Singapore)	Kings Dock.		800' 0"	90' 0"		128' 0"	34' 0" H. W.								Yes [illegible] 25, 480'
Germany	Bremerhaven.		869' 10½"	113' 2"	115' 6"								1908.	$1,915,00[illegible]	
Ireland	Belfast.		887' 0"	96' 0"		128' 0"	35' 3" H. W. O. S. T.		Sliding gate. (Hyd power)		Rock.		1911		
British Africa (Cape Good Hope)		Naval	745' 0"				36' 3" H. W. O S T				Rock.		1906.		Yes: 2 ca[illegible]
Germany	Wilhelmshaven. No 4. No. 5 and No. 6.	Naval.	570' 0"±	101' 0"±		103' 0"±	37' 6" H. W. O. S. T.	Trass lime concrete.					1908.		
France	Cherbourg.	Naval.	781' 0"	118' 0"	118' 0"	174' 0"	32' 6" H. W.		Roller gate.	4 on either side of vert. center of wall from floor level to coping				$6,300,000 00	
France	Brest. (Twin Docks)	Naval	656' 0" 695' 0"	118' 0"	100' 0"±	167' 0"	26' 4" L. W.		Roller gate.	4 on either side of vert. wall.	Rock.	Rock.		$2 509,000.00	
France	Havre.	Commercial.	1023' 0"	124' 6"	113' 0"	173' 2"	36' 4"		Pontoon gate; action similar to rolling	5 on either side of vert. wall.		Alluvial deposit of Seine River		$[illegible]	
Japan Nagasaki	Mitsu Bishe No 3		714' 0"		88' 7"	96' [illegible]									
Italy	Proposed.		1000' 0"		105' 0"										
Italy	Taranto No. 2.		700 to 1000 ft.	106' 0"			M. S. Level 40' 0"	Concrete, lime and puzzolana							
Italy	Venice No 3.		700 to 1000 ft.	120' 0"			M. S. Level 39' 0"	Lime, concrete puzzolana							
England (Liverpool)	Canada.		925' 0"			94' 0"	31' 9" H. W. O. S. T.	Concrete, granite steps and coping.	Mitre gates.		Red sand stone.		1898		
England (Bristol)	Royal Edward.		875' 0"	100' 0"	100' 0"	126' 0"	34' 0" H. W. O S. T.	Concrete, granite and brick.	Caissons, floating ship.			Red marl.	1908.	$1,750,000.00.	Yes; 328', 547'
England (Graves End Reach)	Tilbury Dock. (Two Docks)	Commercial.	880' 0"	70' 0"			35' 0" Trinity H. W.	Concrete, granite and facing brick.	Caissons, ship without pumps.	3 altars from center of vert. wall to coping.	"Ballast" gravel	"Ballast" gravel.	1885.		Yes [illegible]
England (Grimsby)	Immingham.	Commercial.	740' 0"	65' 0"			28' 0" H. W. O S. T.	Concrete, Norwegian granite, brindle brick	Caisson, ship.		Bowlder clay.	Bowlder clay.	1910. 65% Finished		Yes 330 920
England (Keyham)	Dry Dock No. 8.	Naval.	650' 0"	95' 0"±		95' 0"	36' 0" H. W. O. S T.	Concrete and granite.	Caisson.	3 altars symmetrically placed on center line of vert. wall.		Hard crystalline lime stone			
England (Keyham)	Dry Dock No. 9. (Double)	Naval.	745' 0"	95' 0"+		95' 0"		Concrete and granite	Sliding caisson.	3 altars symmetrically placed on center line of vert wall					
England (Keyham)	Dry Dock No. 10. (Double)	Naval	741' 0"	95' 0"±		95' 0"	36' 0" H. W. O. S. T.	Concrete and granite.	Sliding caisson.	3 altars symmetrically placed on center line of vert. wall					
England	Chatham No. 9.		650' 0"			84' 0"	38' 4" H. W. O S. T.	Concrete.	Floating steel caissons: no pumps.		Gravel				
Canal Zone	Balboa.		1080' 0"			100' 0"	41' 6" H W								
England	Portsmouth No 15.		607' 0"			98' 0"	34' 0" H. W. O S. T	Red brick and granite.	Floating steel caisson.		Stiff blue clay				
England	Bracklebank.		796' 6"			93' 8"	31' 7" H. W. O S. T						1906		
England (Avonmouth)	Bristol.		850' 0"			100' 0"	32' 0" M H. W.	Concrete, brick and stone.	Floating caisson			Silt and mud over marl	1908		Yes.
Scotland	Rosyth.	Naval	850 ft +			117' 0"	41'+ M. H. W.	Concrete and granite.	Sliding caisson			Laminated sand stone			
[illegible]		Naval.	790' 0"			95' 0"	35' 6" M. H. W.	Concrete, lined with granite.	Sliding caisson.			Seamy water bearing rock.	1908.		Yes

(e) Dock with ship, major limits weight of back-fill and steepest angle of repose.

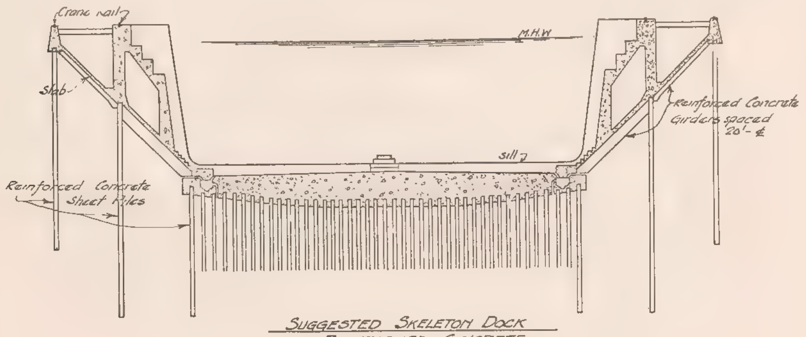
(f) Dock with ship, minor limits weight of back-fill and flattest angle of repose.

It is, in most cases, impossible to develop a practicable cross-section which will give lines of pressures, within the middle thirds of joints for all of the above conditions. By reinforcing critical sections, increasing the bearing power of the earth with piles, utilizing pile pull, by keeping the tension in concrete within safe limits, and by making reasonable assumptions regarding the action of stresses, a section can be obtained which will satisfy good practice requirements and furnish ample safety for all conditions of service. As a general criterion it may be stated that a dock section is safe if, in order to fail, the condition of loading must undergo changes which will bring the line of pressure within the middle third of assumed joints. To illustrate, let it be supposed that, under an assumption of uniform bottom bearing, the line of pressures falls outside of, and below, the dock section at the center. This indicates probable failure by upward movement and consequent rupture of the floor at this point. The slightest movement in direction, however, nullifies the assumption of uniform bearing, increases soil loading under the side walls, reduces the soil loading under the center, and induces a passive lateral thrust against the rear face of side walls. If, under these conditions, the line of pressure is raised until it passes through the middle third, the structure may, other conditions remaining favorable, be deemed a safe one. It may, and probably will in most cases, become necessary to reinforce the bearing value of the soil in order to take care of the additional loading thus brought upon it.

For mass concrete, a 1:8 mixture may be used. The back and face of side walls and floor slab should be 1:6 for a depth of at least 12 inches, and large stones may be placed in the mass work under limitations as to position and depth of bedding. Docks are often built of coarser mixtures than 1:8, but in water-bearing materials it is believed that the attainment of impermeability by a richer mixture will prove a good investment by the assurance it affords of increased durability. When the

amount of water to be expected is small, economy can be attained by embedding "bleeder" pipes in the floor and walls to relieve hydrostatic pressure.

In concluding this attempt to outline American dry dock practice, it should be stated, by way of apology for its shortcomings, that a comprehensive treatment of so broad a subject cannot be compressed within the limits of a professional paper. The task was only undertaken in the hope that it might result in a profitable discussion of a most important class of works by engineers whose opinions carry weight. That it deals principally with naval structures is due to the fact that, lacking a



SUGGESTED SKELETON DOCK OF REINFORCED CONCRETE FOR COMMERCIAL PURPOSES.

Fig. 20.

merchant marine worthy of the name, American docks of large size have either been built directly, or materially assisted, by the military branch of the government.

A merchant marine must come in time and with it must come docking facilities. When this occurs engineers will face the problem of providing structures of less cost for commercial uses. It is reasonable to presume that the ingenuity of designers will keep pace with the demand, whether it be by adopting the principle of the old Simpson timber docks, as is suggested in Fig. 20, or by more radical innovations.

In connection with the rapid growth of ships and docking facilities, it may be of interest to recall the fact that some eight years ago, in discussing a paper read before the American Society of Civil Engineers*, Mr. L. J. LeConte advocated docks

* "The Naval Floating Dock—Its Advantages, Design and Construction", Trans. A. S. C. E. Vol. LVIII.

of from 900 to 1000 feet in length. The present writer, who now recommends lengths of 1300 feet, in a reply to Mr. LeConte's discussion, opposed such dimensions as "extreme". A similar reception was accorded to the prophesies on dimensions of future ships made by Mr. E. L. Corthell at several meetings of the International Congress of Navigation held during recent years. No man can foresee the requirements of the future and the engineer who would build for all time must needs be a dreamer of dreams.

DISCUSSION

Mr. H. P. Frear,‡ Mem. Soc. N. A. & M. E., pointed out the wide importance of the subject of the paper, not only to the vessel owner and operator, but also to those dealing with the design and operation of dry docks. He agreed with the author in the continued tendency of ships to outgrow docking facilities, and in the importance of forecasting, if possible, the growth in size of ships and of providing sufficient size of dock for any reasonably anticipated growth in size of ship. Mr. Frear.

Referring to the type of caisson, Mr. Frear noted a somewhat similar construction some 30 years ago by the Union Iron Works Co., of San Francisco, for the Mare Island Navy Yard, but in which the watertight floater was at the top instead of a little above mid-height, and on this account it was necessary to handle a much greater volume of water in submerging and floating the caisson.

Mr. Frederick R. Harris,* M. Am. Soc. C. E., wrote that he believed, generally speaking, under the most favorable conditions, a graving dock is less expensive in first cost than a floating dock. The cost of floating docks would vary somewhat, but would generally be between the following limits: Timber, solid trough type, $28 to $35 per lift, long ton; timber, sectional type, $25 to $32 per lift, long ton; timber, pontoons, steel wing walls, $42 to $48 per lift, long ton; steel sectional or solid trough, $52 to $65 per lift, long ton. These were for the floating dock complete, but took no account of the cost of the necessary work required in connection with them, such as piers, approaches, dredging, etc. A proper comparison of the cost of a floating dock with that of a graving dock would on this basis have to consider the probable maximum displacement of a ship that could be docked in the graving dock. On this basis, the cost of the naval dock No. 2 at Boston, Mass., was $28.80 per ton; the estimated cost of the Boston State dock, granite walls, $28.09 per ton. The highest cost of any United States dry dock, on this unit basis of comparison, was that of Dry Dock No. 4 at the New York Navy Yard, $49.70 per ton. This was an expensive structure on Mr. Harris.

‡ Naval Architect, Union Iron Works Co., San Francisco, Calif.

*Corps Civil Engineers, U. S. Navy, Navy Yard, Philadelphia, Pa.

Mr. Harris. account of the unusual foundation difficulties, involving an expenditure of nearly a million dollars for pneumatic caisson work, independent of the other work.

Mr. Harris thought he would probably be correct in stating that a graving dock can be built practically any place. However, the more unsuited the location as regards foundation and other conditions, the more costly would be the structure. One of the principal advantages of a floating dock, in a commercial sense, appeared to be that it is not a fixture, and in case of large enhancement in property values and other changed conditions, the floating dock may be towed away and removed to a new site. He did not entirely agree with the author's statement under "Number of Sills", as he had just completed a most careful study and investigation of the proposed dry dock for the port of Boston, and as a result of this investigation it appeared desirable to include in this dry dock an intermediate seat, so that the inner portion might be employed for moderate-sized ships. The question as to the employment of both the inner and outer sections for two ships was recommended to be left in abeyance, as it seemed doubtful whether occasions would frequently arise when the dry dock could be so used. However, the economy in pumping to be obtained by using the inner chamber, when possible, would be quite considerable—about 20% of the net annual earnings. Basing figures on the vessels regularly visiting this harbor and owned by the three transatlantic steamship lines that proposed subsidizing the structure, the saving was sufficient to pay for the additional cost of the intermediate seat in two years.

With regard to pumping plant, he stated that, with the assistance of Mr. DeWitt C. Webb, he had made an investigation of the form of power for pumping the Boston State dry dock, involving a 4000-brake-horsepower installation. The cost of electric-motor drive and accessories was estimated at $50,000.00; condensing engines, $247,560.00; steam turbine (reduction gear), $238,920.00; Diesel engines, $211,000.00—the cost in each case including foundations, buildings, flues, stacks, boilers and auxiliaries. On the basis of this and further studies, preliminary curves were prepared, showing the comparative costs of operation with and without fixed charges, such as depreciation, interest, repairs, etc. On the basis of 60 double pumpings per year, Diesel engines were more economical than electric motor drive at 2 cents per kw-hr., and horizontal condensing engines or steam turbine with reduction gear slightly more expensive than electric motor drive at 2½ cents per kw-hr. On the basis of 80 double pumpings per year, Diesel engines were more economical than electric motor drive at 1½ cents per kw-hr., and horizontal condensing engines or steam turbine with reduction gear slightly more economical than electric motor drive at 2 cents per kw.-hr.

In preliminary exploration borings, Mr. Harris believed it was of the greatest importance to ascertain carefully the water-bearing characteristics of the sub-soil, and that, where possible, core borings should be made, either by the driven-pipe method or by the employment of a

Mr. Harris.

double-core-barrel rotary drill. He said that observations of the water-bearing characteristics could be made by application of water pressure at various levels in the casing pipe and noting the loss in a given time.

He thought that full hydrostatic pressure or uplift would be developed beneath most completed graving dock floors, unless this were relieved by sub-floor drainage with bleeder pipes. A careful series of tests, with pressure gauges and specially constructed dynamometers, in Dry Dock No. 4 in New York gave complete evidence after the completion of this dry dock that the full hydrostatic uplift was active under the floor.

Dr. Luiggi.

Dr. Luigi Luiggi,* M. Am. Soc. C. E., wrote that the author has put in condensed form the most important and up-to-date methods and recommendations to be kept in view by an engineer when designing and constructing a modern graving dock, either for naval or commercial purposes or both. The best European maritime engineers could endorse Mr. Cox's views. The author's advice on the design of cross section to suit the location and character of the supporting soil, on the calculation of dimensions for various parts, on the materials to be employed, and on all the other details and accessories, could be fully accepted and recommended.

Dr. Luiggi thought the cross-section foreseen for future commercial graving docks, in which economy is most important, rather bold for the European ideas, but quite rational. The recommendations foreseeing the needs of future shipping he thought quite prudent and to be insisted upon. He had built a graving dock in 1896-1910 in the military port of Bahia Blanca in Argentina. This dock was 720 ft. long, 95 ft. wide, and 35 ft. deep at the sill. In those days it ranked amongst the largest in the world. There was complaint that the designer and builder had exceeded any reasonable need and had expended money that could have been saved. That dock is now small for the Argentine battleships "Rivadavia" and "Moreno" and a new one, 850 ft. long, 125 ft. wide, 38 ft. deep below O. H. T. is being built alongside the first. The new dock is arranged so that in the future it can be lengthened to 1,400 ft. and provided with two entrances and an intermediate gate so as to divide it into two distinct docks. Dr. Luiggi said that he advised, in 1910, the construction of naval docks at Taranto and Venice, 850 ft. long, 120 ft. wide at the entrance, and 39 ft. deep. An accident to the Italian battleship "San Giorgio" demonstrated the utility of being able to dock a sinking ship together with the pontoons that keep her afloat. Therefore, for Taranto, where the change was still possible, the entrance was widened to 135 ft. This makes the Taranto dock, now ready for service, one of the largest, if not the largest, in the world. Both the docks of Taranto and Venice can be lengthened to 1,100 ft. Dr. Luiggi expressed the opinion that the future would bring bigger ships, that graving docks should be at least 130 ft., and preferably 150 ft., wide at the entrance, of such length as to fulfill present needs and capable of

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Dr. Luiggi. lengthening easily in the future without disturbing the part previously built. He stated that floating caissons are the cheapest. In places where the tide is small, 5 ft. or less, they should without doubt be preferred. Where the range of tide is great, more than 10 to 20 ft., it appeared worth while to make a comparison between floating and sliding caissons, notwithstanding the fact that the latter involve an expenditure four to five times greater because of the costly masonry for the recess. He said the sliding caisson is always sure in its operation, and can be closed in two or three minutes, so that whatever may happen it can always be put in place. The floating caisson in a tidal harbor is subject to accident. When building the first graving dock at Bahia Blanca, he had docked a battleship before the sliding cassion was ready, using one of the floating caissons made for the inner sills. The ship was in the dock and the caisson was being placed. A piece of wood jammed the caisson on one side and it was difficult to move it. The tide was rapidly receding and the ship was not exactly placed on its bilge blocks owing to the fact that the attention of workmen was required in freeing the jammed floating caisson. A dangerous hour was past before all was put straight. The tide had a range of 12 ft. There was fear that the ship might be injured. With a sliding caisson Dr. Luiggi believed there would have been no danger, as, since 1902, there had not been the slightest difficulty in operating the sliding caisson at Bahia Blanca. Sliding caissons have, therefore, been adopted for the new graving dock there, now nearly completed. Dr. Luiggi thought the greater expenditure in the case of a naval dock fully justified by the absolute security of maneuver. He expressed the opinion that graving docks are to be preferred above floating docks in all normal cases. The floating docks, he thought, are desirable in exceptional cases or great urgency, or where there may be great difficulty with foundations. In the case of Venice, where the bottom of the lagoon is of silt, mud and sand, so that foundations were very costly, a floating dock was proposed at first, made of ferro-concrete, a novel but quite practical idea. For 30,000-ton battleships, the proposed dock required a basin dredged to 65 ft. in order to receive a ship with 40-ft. draft. The difficulty of keeping this basin free from silt was so great that notwithstanding the enormous difficulties in the way and the greater cost of a masonry graving dock, owing to bad foundation, the idea of a floating dock was discarded. The graving dock of Venice was built of concrete by means of compressed-air caissons, a method costly but apparently successful. Dr. Luiggi had used this method in ,a construction of the two graving docks of Genoa, in 1888 to 1892, and has since used it in Naples, Palermo, Caraccas, etc.

Mr. Box. **Mr. Edward Box,*** M. Inst. C. E. (by letter), congratulated Mr. Cox on preparing such an excellent paper upon "American Graving Dock Practice," and he can only express his regret that it was not possible for him to be present to take part in the discussion. As Mr. Cox points

*Consulting Engineer, Newcastle-on-Tyne, England.

out, there must often be an element of uncertainty as to the desirable dimensions a dry dock should be built to. Mr. Box suggests that for commercial purposes the particular trade the district is in touch with will have some bearing upon the decision. Mr. Box.

We, as dock engineers, should be able to solve all the problems necessary to be solved to enable ships of whatever size it may be deemed necessary to build to, being safely and expeditiously dry-docked. The choice of dock, graving or floating, should be left to the engineers to advise, after they have had an opportunity of thoroughly investigating the site.

For the larger type of graving dock, the selection of a suitable site is of considerable importance, varying, of course, with the local conditions, such as the rate of flow and set of the tide—both being important factors in the selection and arrangement for a particular site.

With the smaller types of graving docks the question is not such an exacting one. Where the flow of the tide is at all moderate, graving docks are built in this country at varying angles, as the particular site may require.

It would appear from the description of the several docks described by the author, and from what Mr. Box knows of American practice, that the method of open excavation behind a cofferdam is favored more in America than in England, where the usual method is to trench the side walls and then excavate the center portion, following up the excavation with the concrete floor. This method is regarded as the safer, sometimes the only practicable one.

With regard to docks subdivided by internal gates, such an arrangement has not gained general favor in England, as it does not lend itself to quick despatch. Docks in busy shipping centres are usually built in groups of varying size, as particular business developments may have shewn to require.

On the other hand there may be exceptional circumstances where a divided dock would be correct, as for instance, on the Great Lakes of America, where the writer prepared a scheme for a dock-yard establishment, adopting a divided dock—the dock being required to accommodate vessels of considerable range in size.

With regard to the method which should be adopted for closing a graving dock—here, again, the local conditions will require to be considered. Where the tide has but little or no variation in level, the ship type of caisson is simple and efficient. Where, however, the tide has considerable range, as at most shipping ports in the British Isles, the question is more complicated and gates for commercial docks are more generally adopted.

The author points out that the older docks "were equipped with gates, but these were later abandoned and caisson seats installed."

The writer is, it may be interesting to note, at the present moment dealing with a series of docks where, in the case of the narrower docks

Mr. Box. of the group, ordinary gates were abandoned and "flaps," or drop gates, were installed; and in the case of another dock of the same series, having an entrance of 84 feet closed with a ship caisson, it has been decided to abandon the ship caisson and install the flap caisson. This is due to local conditions. These docks are in an exposed position and are subject to a variation of tidal range of from 14 to 28 feet.

Under such conditions, the ship caisson is not by any means a desirable method of closing a graving dock.

There are many points in detail, dealt with by Mr. Cox, such as the most suitable material for sills and quoins. Mr. Box has used both granite and greenheart with satisfactory results.

As a material of construction, concrete continues in this country to be the material used, either in bulk or partially reinforced with steel rods—"mass concrete reinforced." Granite is being used less as a material for lining purposes.

Blue brick linings for the side walls are in favor in this country with some engineers, and certainly make an excellent job.

Mr. Parks. **Mr. C. W. Parks,*** M. Am. Soc. C. E. (by letter), states that the author has made two statements relative to Dry Dock No. 2, Boston, and one or two relative to Dry Dock No. 1, Pearl Harbor, which are not strictly in accordance with his recollection of the facts.

Dry Dock No. 2, Boston.

Mr. Cox states that this dock cost $1,100,000, and that no difficulties were encountered.

The cost stated is that charged to the appropriation for "Four Timber Dry Docks." Figures are not at hand, but it is Mr. Parks' recollection that an additional sum of $215,000 was paid, in accordance with a judgment of the Court of Claims, which would make the actual cost of dock approximately $1,315,000. This included approximately $100,000 for yard power plant, which was needed to supply electric current to the dry dock pump motors for the reason that no other sufficient source was available. The cost per foot was, therefore, about $1,780.

The only important difficulty encountered was in connection with the cofferdam, which, by the way, was rectangular and enclosed the space outside of the original shore line in which the outer end of the dock was constructed. After considerable discussion, relative to the design of the cofferdam, the contractors built one in accordance with a plan which was satisfactory to the civil engineer in charge. This cofferdam failed, and a much stronger cofferdam was designed and built, which remained in place until the completion of the dry dock.

Dry Dock No. 1, Pearl Harbor.

There was a lack of appreciation of foundation conditions, but the engineer on the site of the work considered the conditions most unfavorable, and took the matter up with the Chief of the Bureau of Yards and

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Docks, in September, 1909, while the Chief of Bureau was at the Station on a tour of inspection. There was a difference of opinion as to the seriousness of the conditions. Mr. Parks.

The 8 to 13 feet of indurated lava mud, mentioned by the author, is above sea-level and rests on a coral shelf. The deposits of lava mud and coral appear to extend to a depth of more than 500 feet below sea-level, as shown by artesian well borings made in this neighborhood. The Naval Station site is on a coral reef, approximately two miles seaward from the original lava shore line of the island.

The specification for the construction of this dock was prepared at a time when it was not known whether supporting piles were necessary or not, and the contract was let for a dock without piles. At a later date, test piles were driven and the decision was reached that piles were unnecessary. Still later, plans were changed and provision was made for driving piles 35 feet into the underlying strata. Four feet of pile head were to be embedded in concrete. It was expected that piles having this penetration, together with the weight of 8 feet of concrete, would be sufficient to withstand the hydrostatic head during unwatering. The average length of pile driven was much less than 35 feet, and the average thickness of concrete was much less than 8 feet at the time unwatering took place, and the dock failed. As the piles were not embedded 35 feet in the underlying strata, and the concrete was not 8 feet thick, the question as to whether this method would have been sufficient cannot be definitely settled.

Early History.

Mr. Parks' duty in connection with the Dry Dock Board in 1897, and the Bureau of Yards and Docks in 1898 and 1899, enables him to give a little of the early history of the dry docks at Portsmouth, Boston, Philadelphia, and Mare Island, which may be of interest.

The general dimensions of the docks were determined by a Board of Officers in 1897, and the precept called for the dimensions for docks having a capacity for battleships of 20,000 tons displacement.

At that time, the largest battleships authorized for the United States Navy were the "Alabama" and "Illinois," which have each a displacement of 11,552 tons. It was found difficult to secure from the designing bureau the midship section of a 20,000-ton battleship, and the section used was one developed by the Board. One member of the Board believed that a ship over 400 feet long would be too long for battle maneuvers, and that one drawing over 23 feet would be kept out of too many of our harbors. The beam of a 20,000-ton battleship 400 feet long and 23 feet draught was used to determine the width of the dry dock. This gave a wider entrance than needed by our present 20,000-ton battleships, which are 510 feet long, 85 feet 2½ inches beam, and 28 feet 10 inches draught. Battleships of 27,500 tons displacement have been docked in one of these dry docks.

The Board reported, September, 1897, that four new concrete docks

Mr. Parks. and one steel floating dock were urgently needed, and that three other concrete and two floating docks were necessary to place the docking facilities of the country on an adequate footing.

Congress, in the Act of May 4, 1898, authorized the construction of four timber dry docks, and authorized the Secretary of the Navy, in his discretion, to build one of said docks of granite or concrete, faced with granite. The Act provided that the docks should be not less than seven hundred feet in length. The same Act authorized one steel floating dock. Congress, at later sessions, provided for all of the graving docks to be built of granite or concrete. Since 1898, Congress has appropriated for four more graving docks on the continent, one graving dock at Pearl Harbor, one floating dock for the Philippines, and for the purchase of the Havana floating dock. These practically meet the needs of 1897, as given in the Board's report.

Pumping Plants.

The pumping plants of the earlier naval dry docks were engine-driven centrifugal pumps, located in shallow wells, and gave considerable trouble if pumping were suspended when a dock was more than half emptied.

In view of this experience, it was decided to adopt electric motor-driven pumps for the new docks and to locate the pumps lower than the floors of the docks.

Vertical-shaft pumps were thought to be the most desirable and plans for such pumps were undertaken. Some trouble was experienced in designing a satisfactory bearing, but prospects appeared to be good, when the one who had been developing the design was incapacitated by a serious illness. Before his recovery, circumstances made it necessary to hurry plans, and the simpler horizontal-shaft pumps were adopted. The development of the vertical-shaft pumps for United States naval docks was delayed until 1911.

The design of a dry-dock centrifugal pump is not simple, as such a pump starts with friction-head only. The static head increases continuously from zero to a maximum, dependent upon the depth of the dock, the rate of pumping, and the fall of the tide. It was decided to design the pumping plants of a capacity to empty the docks in approximately two hours. The form of impeller at Boston and Portsmouth was intended to have maximum efficiency when depth of water in the docks had been reduced to seventeen feet.

The first design contemplated the use of variable-speed motors to start at a low speed, have a maximum speed at seventeen feet and a decreasing speed from that point on. After the contract was let, the motors at Portsmouth were changed to constant speed and a speed which proved to be too low for the work. After the first test, the pole pieces were changed and a higher and more satisfactory speed secured. Variable-speed constant power-input pumps were first actually built and used in an English dry dock about ten years later.

After letting the contract, the Boston pumping plant was changed from three 42-inch pumps, driven by direct-current motors, to two 48-inch pumps, driven by alternating-current motors. While the pumps are 48 inches, the discharge is expanded to 54 inches just beyond the pump. Mr. Parks.

Mr. W. H. Pretty,* A. M. I. C. E., by letter, said that the paper as a whole and as presented by the author draws the reader's attention in a concise form to various graving docks already built or under construction. Such records are valuable for reference, and of particular interest at the present time in view of the inevitable changes that must follow the present conflict. Mr. Pretty.

The dimensions or capacity of graving docks in their initial conception are perhaps more ''personal'', so to speak, than for floating docks, since the latter can be built in sectional units of relatively large transverse dimensions, additional units being added to secure extra length or buoyancy as future requirements may demand. In the case of graving docks, in view of their cost, it is not unreasonable to expect that engineers may be asked to limit the dimensions or capacity to cover the estimated requirements of the navy or mercantile marine for the next decade only. It should not be forgotten that a graving dock, once constructed and well equipped, is relatively a more valuable asset than a floating dock, although it is, in the writer's opinion, not too much to say, that no port can be said to be completely equipped that does not possess both types, the mobility of the floating dock placing it in a class by itself. Neither should the fact be overlooked that the economic handling and dry-docking of small merchant craft forms no mean factor in building up a port and its commerce with the outside world.

One cannot contemplate the growth in dimensions and capacity of graving docks without serious thought upon the subject of possible departures from recognized standard designs. For instance, the writer would suggest the consideration, as occasion may arise, of what may be described as an ''off shore'' graving dock, the dock centre line being parallel to the stream or channel, the inner or shore wall forming a part of the shore wharf and the outer wall being towards mid-stream, or mid-channel, caisson gates being used at each end and an intermediate caisson and sill being provided, not necessarily central in the run of the dock length. At first sight it would seem that roller caisson gates running into recesses in the wharf, below the coping level, would be the best to adopt for this proposed type of graving dock. The independent use of the two component chambers of the dock is thus assured.

Again there may be cases where it might be worth while to consider an ''entrance lock'' to a graving dock, the floor of the latter being fixed at some predetermined height above the lock sill, water being pumped up (if necessary) for locking through. The lock would be used as a wet dock for various craft which could readily be floated out of the way when locking ''in'' and ''out'' of the graving dock.

* Cons. Engr., Peterboro, Ont., Canada.

Mr. Pretty. There may be troublesome locations where the building of graving docks could be accomplished, and hazard otherwise serious, almost, if not entirely, eliminated by building a composite dock, the lower portion of the dock, including the floor and a portion of the side walls, being a sectional pontoon; the sections being floated over the site after preparing the bottom bedding to receive the dock. The side walls could then be built up of concrete or masonry, etc., in the dry; wells or shafts being left in the side walls for carrying down concrete, etc., when ready to complete the lower portion of the dock mass. Special double grouting pipes and grouting holes for depositing under pressure or by tremies might be advisable for reaching the dock bedding or interior of pontoon under dock floor.

In dealing with the relative cost of graving docks, would it not be better to compare costs in reference to total docking capacity in cubic feet, say, as measured between the side walls from the dock floor level to coping level, the unit of reference being the cost per cubic foot of capacity so measured? A schedule of prices for "materials" and "labor" in force during construction should also accompany the general statement of cost for any particular dock.

The writer would suggest that a little more description accompanied by photographs and sketches on the subjects of "sills" and "caisson grooves" would add greatly to the interest of the paper. The question of unwatering and making water-tight seals at joints must ever remain somewhat of a religion with those who have to cope with them on a large scale.

The flooding of graving docks through the drainage culverts in the side walls, and which communicate by pipes with the dock near the floor level, is perhaps the best plan and is that now generally adopted for filling and emptying the chambers of canal locks.

Under the author's interesting statements regarding the satisfactory use of vitrified brick for the lining of Dock No. 4, Navy Yard, New York, a few particulars of the brick used, such as specific gravity, approximate chemical composition, colour, size, surface hardness, porosity as measured by absorption of water under pressure, crushing strength, uniformity in quality, etc., would be acceptable.

In considering the keel blocks, it seems unfortunate that ocean-going steamships are not yet generally designed to facilitate docking on two or three lines of keel blocks. There are many ways of looking at this question, and perhaps some attendant disadvantages. The writer's impression, however, is that dock masters generally would welcome such a course, since their three lines of keel blocks would enable them to dock on one, two, or three lines of block, as the various craft might demand. Would it not be well to make the upper layer of keel blocks of softer wood, which could be thrown away between successive dockings? Such a course would tend to automatically relieve the ship and dock from ex-

cessive local stresses long before the adjoining folding wedges could be driven home. Mr. Pretty.

The subsurface exploration of the proposed dock site, to which the author has drawn attention, is too important to pass by without notice. If possible, the trial borings should be, in the first instance, preferably external to the area to be occupied. The results from these trial borings will enable the engineer to anticipate the results of trial borings yet to be made in the dock bed itself. If the presence of artesian pressure has been revealed in the external borings, it is, generally speaking, advisable to avoid tapping these within the area to be occupied by the base of the dock.

The author's criterion for a safe dock section is clever, and although a necessary condition for stability under assumedly possible movements, is interesting as a statement and compels attention.

The use of "bleeder" pipes in the floors and walls of all engineering structures subject to hydrostatic pressure should, in the writer's opinion, be insisted upon and their positions and extent accurately recorded on the final plans, metal pipes and special stop valves being used where necessary. Pressure tests could then be taken at any time and a log book kept, from which curves could be drawn up showing at a glance a complete history of hydrostatic pressures. Similar bleeder pipes give valuable information regarding the internal state at known points within the structure itself. It may not be out of place here to say that many dams on inland rivers which have failed could have been saved and "the penticost of calamity" avoided had those in charge possessed information so easily provided by the above means.

The history of the development of the "dry dock" or "wet dock" and of drainage problems in general, is almost the history of the development of the centrifugal pump in its simplest form, and might reasonably give rise to the statement that they are interdependent. Academic ideas of efficiency may receive a rude shock, but the general, all-round qualities of simplicity in construction and reliability (when properly installed), outweigh academic shortcomings where large volumes of water have to be dexterously handled with speed. The choice of horizontal or vertical shafts for the disc impellers is quite arbitrary and ruled by local considerations only. Generally speaking, we may say that the vertical shaft, with the disc impeller at its lower end placed in the sump of the well, and always flooded, direct connected through its vertical shafting to its motor placed at or above the coping elevation well above high water mark, is to be preferred, as the author has pointed out. The vertical shafting must be extra strong to resist torsional stresses and cross bearings placed at intervals down the well, the whole vertical load being carried by a "thrust" bearing of the marine type, now however actually in use as a "suspension" bearing. Motors specially designed for the purpose, may be of almost any type of steam engines, electric motors, hydraulic turbines, internal combustion engines, etc. If each pump is placed in its own well with its disc im-

Mr. Pretty. peller placed in the sump below the dock floor level, and its discharge carried above high-water mark, no valves are necessary, and the little extra head thus involved is not worth considering in view of the simplicity of the installation and the fact that only occasional and intermittent pumping is demanded from the pumps.* The writer has designed pumping plants for large naval dry docks of the type just described—steam-engine driven, direct connected through vertical shafts to disc impellers of the single inlet type and discharging directly into the pump well above the impellers, the suction inlet to the disc running in an opening formed in a diaphragm fixed in the well.

The question arises, however, when considering dock pumping plants, whether it would not be more economical to build a dock "power station" giving 550 volts, 3 phase, 60 cycle supply and which need not lie idle during intervals between the dock pumpings, since it could be used for the general purposes of light, heat, power and traction around the dock, and by using step-up transformers, for transmission purposes to remote corners of the dock yard or as might be desired. Should such a power station be under consideration at any time, the judicious use of a combination of synchronous motors with the asynchronous motors should not be overlooked for improving the power factor at the generating plant.

There are various general items dealt with by the author, which the writer has considered in his contribution to the discussion on the paper by Rear-Admiral H. R. Stanford, U. S. N., on "Pearl Harbor Dry Dock" recently read before the American Society of Civil Engineers, and, with the author's permission, the writer would ask those interested to consult the above paper and discussion.

Mr. Cox. **Mr. Leonard M. Cox,** in his closure of the paper, said that the type of caisson referred to by Mr. Frear has been long abandoned by the Navy Department. Considerable study has been given the development of caisson designs, both as regards first cost and economy of operation. In America, perhaps the most satisfactory type is the so-called "Hydrometer" type in use at Dry Dock No. 4, Navy Yard, New York, N. Y., and the new dock at Puget Sound, Wash. As Mr. Frear is the designer of the new dreadnaught dry dock for San Francisco, it is regretted that he did not describe the type of closure for this dock and the considerations which governed his choice.

Mr. Harris's attempt to compare relative first costs of floating docks and graving docks is of interest, but the writer holds the opinion that such comparisons can have little value unless accompanied by a full statement of all the assumed items of cost upon which they are made. The question naturally arises whether the value of real estate, the cost of dock cranes, crane tracks, and caissons, and other auxiliary appliances and structures should be included, in the case of graving docks, and, in the case of floating docks, the expense in connection with preparation of berth and moorings,

* Of course the usual unwatering provisions were made, and sluices (simple) in open penstocks where necessary.

cost of land connections, floating or wall cranes and the like. Altogether it would seem that reliable comparisons can only be made for certain particular locations. Another very important factor to be considered in studying the question of relative costs is the special service requirements to be satisfied. For instance, a naval dock may be required to have the quality of stiffness; for commercial purposes much of the steel in the pontoons and side walls of such a dock could be materially lightened. Again, for reasons deemed sufficient at the time, the U. S. S. Floating Dock ''Dewey'' was designed for stresses not to exceed 10,000 pounds per square inch, whereas in many foreign docks stresses exceeding 16,000 pounds per square inch are not unusual. Mr. Cox.

Without reopening the long controversy between adherents of the two types, it may not be out of place to invite attention to one advantage of the floating dock frequently overlooked. For military, or even for commercial purposes, the time necessary for construction may sometimes be so important a matter as to render it the deciding factor. A steel floating dock for modern dreadnaughts can be placed in commission within a year if the occasion warrants the additional expense. A graving dock of modern type could not be completed within two years, at the very least, unless conditions were in every respect ideal. On the whole, the writer approves the findings of the International Navigation Congress—that the selection of type must continue to be a problem for each location, and that while the graving dock is generally desirable, for local or special reasons the floating type may be clearly indicated.

As regards the inclusion in a graving dock design of an intermediate sill, the writer adheres to his opinion that as a rule the resulting economy or increased convenience will not counterbalance the extra cost involved, in the eyes of the commercial dock yard owner. It must be remembered that the double-chambered dock is a novelty in this country and that the opinions of English engineers do not seem to be universally in their favor. If a dock could be entered from both ends, the intermediate sill enables the structure to be used as two independent docks, and therefore such a sill is well worth the expenditure. For a single entrance dock, the one certain advantage of having two chambers is the possible saving in pumping expense. From experience it is believed that the average dockmaster would not realize the full paper saving which computations may promise.

Dr. Luiggi's discussion is valuable in that he gives to American practitioners some definite idea of his latest works. There may be contemporaries who will criticise Dr. Luiggi's opinions as radical, but posterity will surely praise his foresight as a designer and the wise construction policy of his country.

Dr. Luiggi states the relative merits of the floating- and sliding-type caisson very clearly, but it is to be regretted that he did not describe one of his very novel applications of reinforced concrete. The writer understands that he has designed, built, and used successfully, a reinforced concrete floating dry-dock caisson. From such sketches as are available

Mr. Cox. there would seem to be no reason why such a caisson would not be quite as satisfactory as a steel caisson for light draft docks. It offers one great advantage in that it can be constructed by materials ordinarily to be obtained in the open market during such times as the steel plants are unable to make quick deliveries. Dr. Luiggi has also designed floating docks of reinforced concrete, and the writer once attempted to follow him in this direction, but found that the depth of pontoons necessary on account of increased weight would necessitate a maneuvering basin deeper than could be obtained in the particular harbor for which the dock was proposed.

The author concurs in the opinion of Mr. Box, that the choice of type of dock should be left to the decision of maritime engineers. It is assumed, of course, that no engineer would decide upon such a subject, or even offer professional advice, without a thorough investigation of the proposed site and all local conditions. It may be stated as a general fact that, given *carte blanche* as to cost and time, a graving dock can be constructed in almost any conceivable location where there exists a demand for such a facility. Nevertheless, the future earning power of a dock is forever affected by the fixed charges, due to first cost, and by the comparative convenience of approach and entrance. Given a general location, the choice of a particular site may not only govern the whole question of design but may cause the ultimate success or failure of the entire project. As Mr. Box points out, the effect of site is not so important in the case of small docks, particularly those intended for commercial uses.

The so-called English trench method has rarely been used in this country, principally because it limits the scale of operations. Unquestionably, it is safer than the open excavation method in treacherous soils. It may be of interest to state that the trench method was adopted for Dry Dock No. 4, at the New York Navy Yard, during operations under the second contractor; that the method was subsequently abandoned was due to a radical change in design, and not to the impracticability of constructing it by side-wall trenches. In the author's opinion the dock could have been successfully completed by this procedure.

The recommendation to subdivide docks by intermediate gates, or caisson seats, grew out of the recent demand for docks of great length. It is necessary to have long docks to accommodate the longer ships now being built. At the same time, however, by far the greater number of dockings have to do with small ships. The long dock represents an investment made necessary by a demand which may occur infrequently; and yet the dock must be made to earn returns throughout the working year. It rarely happens that a number of small ships can be made ready for docking at one time, and unless such a group of small ships, or one long ship of the dock's capacity, is available, the dock can not be operated economically. With an intermediate caisson, and one or two, or three intermediate grooves, virtually two docks are available with chambers of varying length. By exercising care in placing the "longer time" job in the inboard chamber

and "scraping and cleaning" jobs in the outboard chamber, it is believed that the resulting economy of operation would more than counter-balance the comparatively slight increase in first cost. Mr. Cox.

With Mr. Box's discussion of types of closure, the author is in agreement. As stated in the paper, and also as pointed out in the discussion of Professor Luiggi, the boat-type caisson is not indicated where the range of tide is great.

As stated by Mr. Parks, the cost of Dry Dock No. 2, Boston, Mass., should include all losses or expenses due to litigation brought about by the construction of that dock. The author used the cost as borne upon the records of the Bureau of Yards and Docks. The judgment of $215,000, referred to by Mr. Parks, was rendered, and payment made, a number of years after completion. Mr. Parks' correction is accepted.

In using the language "no difficulty encountered in construction", the author had in mind major difficulties due to foundation conditions and other conditions affecting engineering work of this magnitude. It was not his intention to describe in a general paper of this character, failures of any part of the protection work resulting from inadequate design, materials or methods.

Mr. Parks' discussion of foundation conditions at Pearl Harbor is interesting, in view of the fact that that officer is now serving his second tour of duty on the Pearl Harbor Station, and is, presumably, familiar with local conditions. As this dock has been the subject of a rather thorough discussion in a recent issue of the Transactions of the American Society of Civil Engineers*, it is believed that further reference to the subject would not be warranted in connection with this paper.

Mr. Parks' notes on the early history of naval dry docks in America are particularly interesting, inasmuch as they bring out the fact that upon the completion of the Pearl Harbor graving dock—possibly two years hence—the needs of the Navy as of 1897 are practically met.

The author is inclined to agree with Mr. Pretty's opinion that no port of importance can be said to be completely equipped that does not possess both types of dry dock, the mobility of the floating dock placing it in a class by itself. In this connection it should be borne in mind that the majority of dockings have to do with the smaller class of merchant ships and, as Mr. Pretty intimates, it is this class of ships that forms the backbone of a nation's merchant marine.

With Mr. Pretty, the author believes that departure from recognized standard dry-dock designs is bound to follow the increase in the size of ships, and the consequent increase in the capacity of docking appliances. The author designed a tentative layout for the development of the Norfolk Navy Yard, in 1913, a feature of which was a double-ended, 1400-ft. dry dock, with axis parallel to the waterfront. In this layout, which was not adopted, the location of the dock was governed by the basin and by

* "Pearl Harbor Dry Dock" by Civil Engineer H. R. Stanford, U. S. N., Proceedings Am. Soc. Civ. Engrs., Vol. 41, p. 1093.

Mr. Cox. approach conditions. The principal objection to an "off-shore" graving dock, to use the term adopted by Mr. Pretty, is that it destroys valuable waterfront space, or renders the use of such waterfront inconvenient.

The author has also given some consideration to the "entrance lock" graving dock, as suggested by Mr. Pretty. Several years ago he suggested the possibility of lifting ships by such an entrance lock to a docking floor virtually at mean-low-tide level. The project was considered in connection with a location exceedingly unfavorable for graving dock construction. Its operation would involve the pumping in of water, instead of pumping water out, and, with a single lock, would result in virtually doubling the amount of pumping required. Were there available near the dock site a water supply from a running stream which could be impounded at a suitable elevation, or if a reservoir of sufficient capacity could be constructed at an elevation of 40 feet, and kept full by small pumps running continuously, the difference in the expense of operation between such a lift dock and the ordinary graving dock would be comparatively slight. The expense involved in the first cost of such a structure would be great, however, and no particular advantage would result. The general principle of the scheme might be utilized were it desirable to provide a high-level keel-block floor which could be used either as building-ways or docking platform—such a floor being located adjacent and parallel to an ordinary dry dock surrounded by dam walls and equipped with 80-ft. gates.

The construction of a graving dock by the sectional pontoon method is certainly feasible, though its relative economy would, of course, depend upon the size of the dock to be constructed, as well as upon many other factors. The plan may be briefly described as the sinking of a box-type floating dock upon a pre-prepared foundation, and then filling the interior compartments of the floating dock with concrete.

The suggestion of Mr. Pretty that there be adopted some uniform basis of comparing costs of dry docks is most heartily endorsed. If engineers would agree upon some arbitrary basis of measuring graving dock capacities the work of reading technical literature having to do with this type of structure would be materially decreased. The scheme proposed by Mr. Pretty would answer every purpose and the author, for one, would like to see something of the kind definitely adopted.

Complying with Mr. Pretty's request for further information concerning the brick used for the lining of Dry Dock No. 4, Navy Yard, New York, Mr. Cox gives the following chemical analysis: Silica (SiO_2)—65.67%; alumina (Al_2O_3)—19.71%; iron oxide (Fe_2O_3)—9.94%; lime (CaO)—2.83%; magnesia (MgO)—1.97%. Color, dark red; specific gravity, 2.2; weight, 9½ pounds; absorption, 1.15%. The bricks were uniformly hard and sound. They were carefully graded on delivery for face and header bricks. Bricks were laid in Old English bond, beds and joints ⅜-inch thickness. At intervals the lining was built back into the concrete space in the form of dovetail keys.

Mr. Pretty's discussion of the question of keel blocks for the larger

ships, sub-surface exploration, and the use of bleeder pipes, is of interest. The practice of inserting bleeder pipes in dock appliances, making one or two readings upon the completion of the dock, and then sealing over the pipes, is bad. Bleeders should be left in commission throughout the dock's life and a fairly continuous record of pressures maintained. Mr. Cox.

In no American dock pumping plant, so far as the author is aware, are multiple-stage centrifugal pumps used in connection with unwatering. Heretofore, the capacity of the single-stage centrifugal pump decreased appreciably as the head increased with approximately constant horsepower input. The pumps of more recent design, however, have small clearances between the impeller and casing which insure practically constant discharge capacity at any head between zero and 40 feet, the horsepower input increasing with the head. Recent designs are also more efficient, more rugged, and more dependable under service conditions than the type of ten or twelve years ago.

At most points where graving docks are located, a power plant is installed to serve not only the dry dock, but the yard and shops as well. Where yard, shops and ships may be served at voltages of 110 or 220, and where military or other considerations do not enter into consideration, it is believed that dry dock power plants should be designed for the production of direct current. This form of energy would enable the use of direct current motors, having shunt field speed control, for driving dry dock pumps, and thus enabling the speed of motors to be so controlled as to permit of the unwatering of the dock down to or below floor level with the main pumps. The direct current motors, it is believed, have a distinct advantage over the constant speed alternating current motors, inasmuch as suction is lost when driving by the latter when the water is about the keel block level, unless the suction connections are located from eight to ten feet below this elevation—a construction which is sometimes impracticable. The same form of energy would, of course, be used to feed the permanent lighting and power circuits aboard the ship in dry dock, and for the driving of shop machines requiring wide speed variation and refinement of control. Naturally this statement is not intended to apply to plants where energy has to be transmitted to comparatively great distances, or where there is a demand for current at various voltages.

Through the kindness of Assistant Civil Engineer Glen H. Burrell, U. S. N., the writer's attention has been called to a number of errors in Table No. 1 of the paper. It should, perhaps, be stated that this table was not intended to include all of the larger docks, though it would now seem that it could, with advantage, have been prepared with such an object in view. It is regretted that in the hurry attending the submission of the paper the table was not more closely checked. The errors and corrections are as follows:

(a) Pearl Harbor Dock:
Length of floor 955 ft., instead of 755 ft.

Mr. Cox.

Width of entrance 121 ft. (M. H. W.), instead of 98 ft., 6 in. (flat floor).

Foundation:

Earth, coral and lava, instead of earth and lava.

Sub-surface conditions:

Earth, coral and lava instead of earth and lava.

Under the column "Constructed" there should appear the legend "Under construction" instead of "Year 1909".

The cost of the completed dock, with all supplemental agreements, \$4,422,000 instead of \$2,567,086.37.

(b) Gladstone Dock:

Under the "cost of completed dock" appears the sum of \$15,000,000. This is in error since it covers the entire layout, including wet basins. This item should be omitted entirely from the table.

Paper No. 222

DRY DOCKS RECENTLY BUILT IN ITALY.

By

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President Italian Society of Civil Engineers
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GENERAL INFORMATION.

The principal Italian ports are sufficiently provided with dry docks for the needs of the navy and the merchant shipping. Among the best and largest may be mentioned the dry docks of the Navy Yard of Spezia, those of the commercial ports of Genoa, built in 1892 by the Author, and the more recent ones of Naples and Palermo: they vary in length from 600 to 720 feet, so that they can admit the largest ships that navigate the Mediterranean.

However, the same could not, until recently, be said of the Navy Yards of Venice and Taranto, which were in need of some modern dry docks capable of admitting the largest super-dreadnought of the present day. So in 1911, it was decided to construct in each of these ports a dock of the following dimensions:

	Taranto Ft.	Venice Ft.
Present length at coping	820	820
The docks may be lengthened to	920	986
Width of entrance at coping	134	120
At mean water-level	133	119
Depth of sill below mean water-level	39.4	36.2
Range of tide	1	2
Time for pumping the dock	3½ hrs.	4 hrs.

A striking feature of these docks, and especially of that at Taranto, is the exceptional width—134 feet at the entrance—which makes it, perhaps, the widest in existence.

This great width was adopted in order to allow the docking of ships in such a damaged condition that they needed the help of lateral caissons, or "floaters", or "camels", to prevent them from sinking.

The advisability of this exceptional width was demonstrated during the salvage operations of the battle cruiser "San Giorgio".

Another important feature of these new dry docks is the great depth of the sill, some 8 to 10 feet deeper than usual, in order to admit ships even in an almost sinking condition.

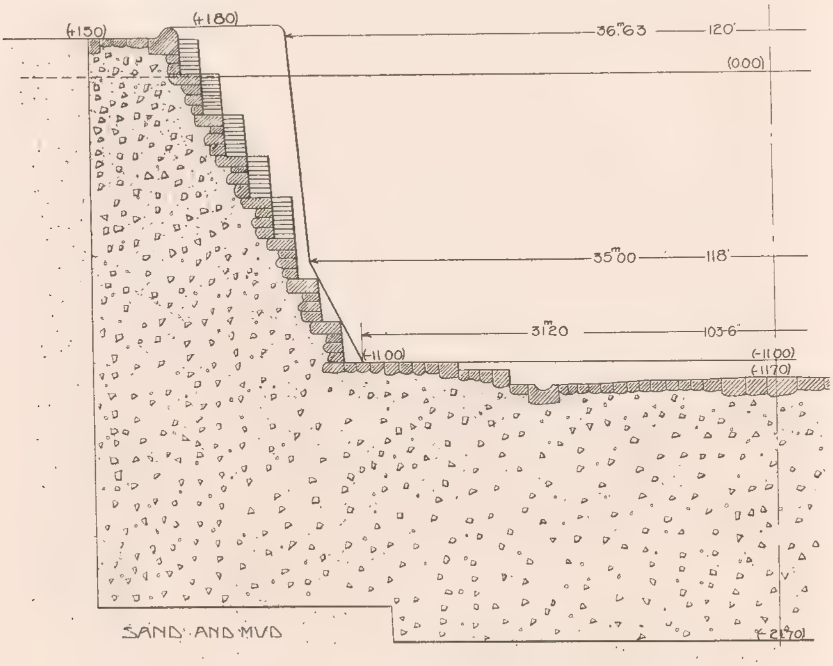

Fig. 1. Dry Dock of Venice.

METHODS OF CONSTRUCTION.

The Graving Dock No. 2, of Taranto, now nearly completed, was constructed inland, without special difficulties and by ordinary methods. It rests on a deep layer of compact clay. The two side walls were built first, between sheet-piling, leaving a central core, which was dug out afterwards in small sections, so that the floor—made entirely of lime and pozzolana

concrete—could be put in as fast as the excavation advanced. Thus the work proceeded without any disagreeable surprise.

The concrete was made of lime, pozzolana and gravel, as is usual in Italy,* and in the proportions of one part in volume of ordinary slaked lime, two parts of pozzolana, from Bacoli, near Naples, containing about 60% of silica, and four parts of stone broken to 2-inch gauge.

As this concrete takes about two weeks to harden sufficiently to allow of another layer being deposited, it was decided to hasten its setting by the addition of 80 kilograms (180 lbs.)

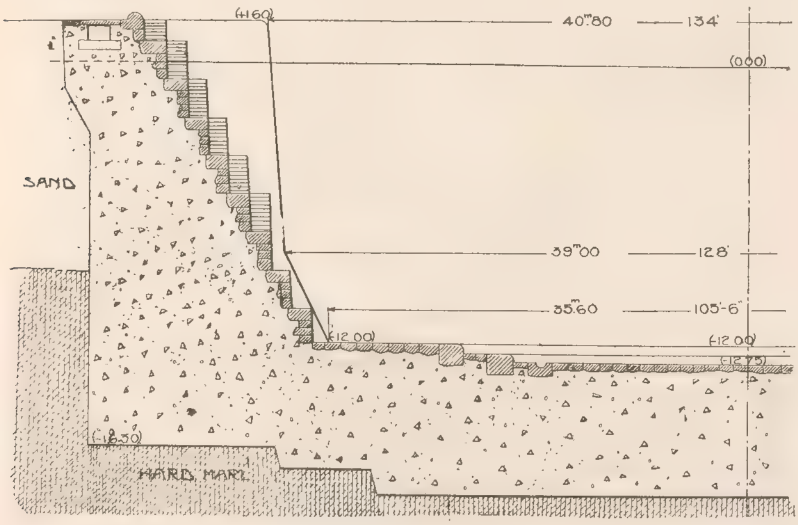

Fig. 2. Dry Dock of Taranto.

of Portland cement to each cubic metre (35.3 cu. ft.) of concrete, which increased the resistance to compression considerably, that is, from 95 to 160 lbs. per square inch after 28 days.

At Venice the dry dock had to be built in the sea, on a foundation of sand mixed with some clay, sufficiently compact, but very permeable. Thus the work was carried out under water, by means of compressed-air caissons suspended from pontoons, which could be raised as soon as a layer of concrete

* For detailed information on this point see "New Experiments on Mortars and Concrete for Sea-Works", L. Luiggi, Giornale Genio Civile, Roma, 1914.

was deposited—some 200 cubic metres of Portland-cement concrete could be laid during the 20 hours forming a working day. This method is very general in Italy; the dry docks of Genoa, Leghorn, Naples and Palermo were all built in this way, without any special difficulty, although at a very great cost. In order to prevent the danger of decomposition of the cement concrete, caused by the slow percolation of the sea-water when the dock is pumped dry, the Portland cement was mixed with some pozzolana. This, being rich in silica, neutralizes any free lime present in the cement and forms a compound which will resist for centuries; as the Roman works of this kind, made with pozzolana mortar, have resisted up to the present time.

The proportions adopted were as follows:

	No. 1 Outer Revetment	No. 2 Inner Core
Portland cement	850 lbs.	550 lbs.
Pozzolana	0.10 cubic metres	0.07 cu. m.
Sand	0.45 " "	0.44 " "
Broken stone	1.00 " "	1.00 " "

The concrete No. 1, for the outer revetment, was made richer in cement and pozzolana in order to be more dense and impermeable. Under a column of water 30 feet high, it does not show any sign of leakage after three days. Its resistance to crushing at 7 and 28 days, respectively, is 1690 lbs. and 2180 lbs. per square inch. The entire dock is faced with ashlar masonry, and the hollow quoins, or grooves, for the caisson are of granite.

Floating Caissons.

The caissons for closing the entrance of the dry docks are of a special type, applied for the first time, in 1892, by the Author at Genoa, and afterwards used for all the similar docks of Italy, and also for the two dry docks at Bahia Blanca in Argentina.

This type is the most simple to construct. The caisson can be easily removed and can be kept in good repair with the least expenditure. Owing to their entirely rectilinear shape and to their structure, they are accessible in every part, including the inner tanks. They are formed (Fig. 3) by two strong beams

A B and C D, united by the plates A C and B D, forming a hollow-beam, which acts, at the same time, as a floating caisson for raising and lowering the whole structure. This hollow

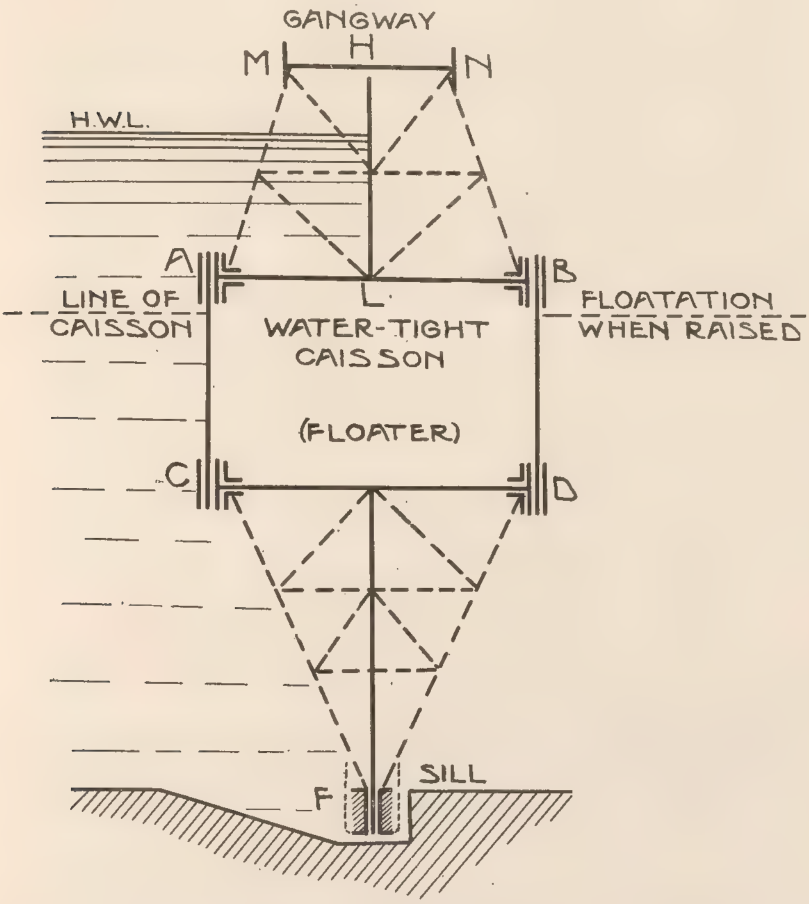

Fig. 3. Diagram of Prof. Luiggi's Caissons Adopted for the Dry Docks of Genoa, Naples, Palermo, Spezia, Taranto and Venice, in Italy, and Bahia Blanca, in Argentina.

beam supports a series of brackets, C D F, resting in F against the sill and affording the necessary rigid support to the iron plates F G.

Above the hollow beam are other brackets, A M L H and H L M B, which support another iron plate, H L, bolted to

another beam, M N, which acts at the same time, as a gangway across the entrance of the dry dock.

The water-tight diaphragm is formed by the plates H L—L A—A C—C G—G F.

The caisson, being symmetrical, can be turned around, so that the face for a time exposed to the sea can be turned towards the inside of the dock for cleaning and painting.

The hollow beam A B C D is fully 8 to 9 feet high, so that every part can be easily inspected and kept in good condition. The raising and lowering of the caisson is done by simply opening or shutting some valves below or above the floating line, according to the position of the caisson, when it is in the grooves or floating. Thus, without the assistance of any special

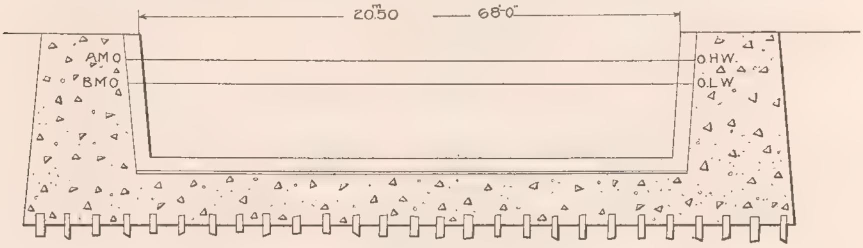

Fig. 4. View of Entrance to Small Dry Dock of Venice.

pump or artificial addition of water, the maneuvre can be performed by a single operator.

The only mechanical appliance is a hand bilge-pump, which is used to draw off the slight leakage that may get inside the hollow beam, through some faulty joint of the plates. The cost of this type of caisson—owing to the extreme simplicity of the structure, it being made entirely of straight pieces of iron as they come from the mills, without any curves—is only about 70% of that of the usual caissons with curved sides; also, in designing the caisson, the calculation for the several straight pieces is more simple and accurate than with curved beams, so that the pressure from the keel of the caisson against the grooves of the entrance can be made almost uniform all around, and kept within the limit of 320 lbs. per square inch, by properly proportioning the height of the hollow beam, A B C D, above the keel of the caisson.

FERRO-CONCRETE FLOATING CAISSON.

Near the large graving dock of Venice, another small, but most interesting dry dock has just been completed. It is to be used for harbour craft, especially for the barges, dredgers, and pontoons used by the various contractors for the ports of the lagoons of Venice. The dimensions of this dry dock are as follows:

Length on blocks	480 feet
Width at entrance	66 feet
Depth of sill at high water	12 feet
Depth of sill at low water	10 feet

A peculiarity of this dock is that its caisson is made entirely of ferro-concrete, with the exception only of the wooden fenders around the keel, where it rests against the grooves of the entrance, and other fenders to prevent any damage by barges bumping against it.

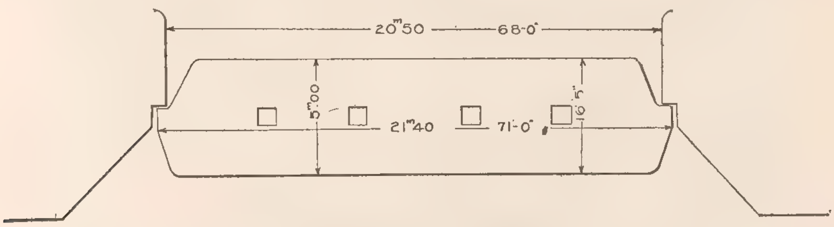

Fig. 5. Plan of Caisson.

Figures 5 and 6 explain sufficiently the shape and structure of this caisson, which is, perhaps, the first of its kind.

It was designed by Chev. Chiera, of the Gabellini Ferro-Concrete Co. of Rome, a firm which has made a specialty of ferro-concrete floating structures, from coal and hopper barges, to ferry-boats of large dimensions.

The advantage of these structures is that they last for many years, even in sea-water; need very few repairs and no painting; and, if damaged by collisions, can be very easily patched with cement; and they cost only half as much as steel caissons.

Barges of this class have been in use in Italy for nearly 10 years and are still in good working condition. They are adapted especially for tropical countries, where iron oxidizes very quickly.

CONCLUSION.

With the completion of the two dry docks, of Venice and Taranto, the Italian Navy Yards will be provided with all the requirements for the docking of ships up to 800 feet in length and 110 feet in width. Ships may be docked even when held barely afloat by means of lateral "floaters". This system up to now, has not been used in any other dry dock. Also the dry docks of Italy offer a special and novel feature in the type of their caissons and they present also the novel feature of a floating-caisson made of ferro-concrete.

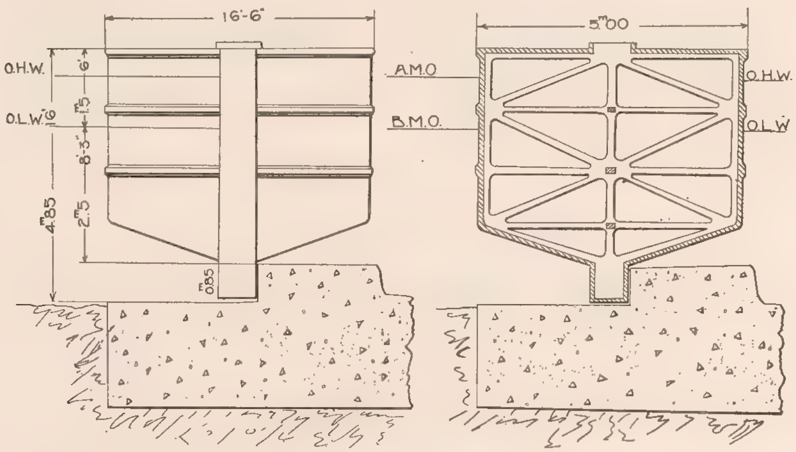

Fig. 6. Ferro-Concrete Caisson for Small Dry Dock of Venice. End View and Section.